UNIVERSITY OF ADELAIDE LIBRARY 13/6/07

# COAL FACIES AND PALAEOENVIRONMENTS OF THE MIDDLE EOCENE TO EARLY OLIGOCENE BOWMANS AND LOCHIEL DEPOSITS, NORTHERN ST. VINCENT BASIN, SOUTH AUSTRALIA

**GAVIN SPRINGBETT**

This thesis is submitted in fulfillment of requirements for the degree of
Doctor of Philosophy

Department of Geology and Geophysics
The University of Adelaide
South Australia

August 2006

## DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and to the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text.

I give consent to this copy of my thesis when deposited in the University Library, being available for loan and photocopying.

18/9/2006

Gavin Springbett

# TABLE OF CONTENTS


| | |
|---|---|
| **CONTENTS** | **i** |
| **LIST OF PLATES** | **viii** |
| **LIST OF TABLES** | **ix** |
| **LIST OF FIGURES** | **xii** |
| **LIST OF APPENDICES** | **xv** |
| **LIST OF ABBREVIATIONS** | **xvi** |
| **ACKNOWLEDGEMENT** | **xvii** |
| **ABSTRACT** | **xix** |
| **1 INTRODUCTION** | **1** |
| 1.1 Background | 1 |
| 1.2 Objectives | 2 |
| 1.2.1 Project aims | 2 |
| 1.2.2 Specific research objectives | 3 |
| 1.3 Research program | 4 |
| 1.4 Thesis organisation | 5 |
| **2 COAL FORMATION, DEPOSITIONAL MODELS AND THE CHARACTERISTICS OF TERTIARY BROWN COALS** | **7** |
| 2.1 Processes and environments of coal formation | 7 |
| 2.1.1 Accumulation of organic matter | 7 |
| 2.1.2 Requirements for peat formation | 8 |
| 2.1.3 Peat forming sedimentary environments | 9 |
| 2.1.4 Coalification | 11 |
| 2.1.5 Factors determining coal type | 12 |
| 2.1.6 Petrographic trends and cyclicity | 17 |

2.1.7 Coal characteristics and palaeoenvironments 19
2.2 Depositional models for brown coal lithotypes 23
2.2.1 Swamp setting 23
2.2.2 Microbiological modification 25
2.2.3 Integrated model 26
2.3 Brown coal evaluation and attributes 27
2.3.1 Differentiation 27
2.3.2 Biomarker content 29
2.3.3 Inorganic constituents 36
2.4 Tertiary coals of southern Australia 40
2.4.1 Occurrence and distribution 40
2.4.2 Conditions for accumulation and preservation 41
2.4.3 Coal types and characteristics 42
2.5 Summary 43

**3 METHODOLOGY AND ANALYTICAL PROCEDURES 45**

3.1 Data availability and gathering 47
3.2 Lithotype evaluation 49
3.2.1 Field lithotype evaluation 49
3.2.2 Laboratory lithotype evaluation 52
3.3 Sampling 53
3.3.1 Sample selection 53
3.3.2 Pre-treatment 53
3.4 Maceral analysis 53
3.4.1 Sample preparation 54
3.4.2 Point counting 54
3.4.3 Maceral indices 55
3.5 Biomarker evaluation 56
3.5.1 Solvent extraction and liquid chromatography 56
3.5.2 Gas chromatography – mass spectrometry (GC-MS) 57
3.5.3 Compound identification 58
3.5.4 Semi quantitative biomarker abundance estimation 58
3.6 Chemical and physical analysis 59
3.6.1 Testing 59
3.6.2 Quartz and kaolinite estimation 60
3.7 Coalfield exploration data 60
3.7.1 Borehole records 60
3.7.2 Seam correlation and assessment 61
3.7.3 Computer modelling 61

3.8 Co-operative research 61

**4 REGIONAL GEOLOGICAL SETTING OF THE BOWMANS AND LOCHIEL COAL DEPOSITS IN THE NORTHERN ST. VINCENT BASIN 63**

4.1 St. Vincent Basin 63
4.2 Coal and geology of the northern St. Vincent Basin 65
4.2.1 Location and relationships 65
4.2.2 History of coalfield investigations 69
4.2.3 Stratigraphy 69
4.2.4 Structure 74
4.2.5 Coal rank and classification 75
4.3 The Bowmans Coal Deposit 76
4.3.1 Seam occurrence and characteristics 76
4.3.2 Seam geometry, splitting and termination 81
4.3.3 Seam boundaries 82
4.4 The Lochiel Coal Deposit 85
4.4.1 Seam occurrence and characteristics 85
4.4.2 Seam geometry and termination 90
4.4.3 Seam boundaries 91
4.5 Coal forming conditions in the northern St. Vincent Basin 95
4.5.1 Bowmans Deposit 95
4.5.2 Lochiel Deposit 99
4.5.3 Regional coal forming conditions 101
4.6 Summary 102

**5 PETROGRAPHIC EVALUATION AND DEFINITION OF COAL FACIES 105**

5.1 Background and strategy 105
5.2 Macropetrographic characteristics 106
5.2.1 Texture 106
5.2.2 Wood content 107
5.2.3 Colour 109
5.2.4 Gelification 110
5.2.5 Hardness 110
5.2.6 Crystalline mineral content 110
5.2.7 Fracturing 111
5.3 Micropetrographic characteristics 111
5.3.1 Introduction 111

5.3.2 Maceral group abundance 112
5.3.3 Tissue preservation 116
5.3.4 Gelification 120
5.3.5 Liptinite assemblage 121
5.3.6 Other parameters 125
5.4 Definition of coal facies 125
5.4.1 Coal lithotypes 126
5.4.2 Micropetrographically-defined coal types 128
5.4.3 Integration of lithotype and micropetrographic evaluations 130
5.4.4 Coal facies of the Bowmans and Lochiel Deposits 133
5.5 Comparison with other brown coal deposits 135
5.6 Summary 137

**6 CLASSIFICATION AND LIKELY DEPOSITIONAL SETTINGS OF THE COAL FACIES 165**

6.1 Facies classification 165
6.1.1 System and nomenclature 165
6.1.2 Petrographic overview 166
6.2 Facies I 168
6.2.1 General characteristics and definition of sub-facies 168
6.2.2 Sub-facies Ia 171
6.2.3 Sub-facies Ib 173
6.2.4 Sub-facies Ic 174
6.3 Facies II 176
6.3.1 General characteristics and definition of sub-facies 176
6.3.2 Sub-facies IIa 178
6.3.3 Sub-facies IIb 181
6.4 Facies III 183
6.5 Facies IV 185
6.5.1 Sub-facies IVa 185
6.5.2 Sub-facies IVb 187
6.6 Likely depositional settings of the coal facies 188
6.6.1 Facies I 188
6.6.2 Facies II 193
6.6.3 Facies III 195
6.6.4 Facies IV 196
6.7 Summary 198

**7 SPATIAL DISPOSITION OF THE COAL FACIES AND IMPLICATIONS FOR TEMPORAL EVOLUTION OF LOCAL PALAEOENVIRONMENTS** **219**

7.1 Ply definition and evaluation 219
7.2 Ply stratigraphy of the Lochiel Deposit 220
7.2.1 H Seam 221
7.2.2 G Seam 222
7.2.3 F Seam 225
7.2.4 Ply boundaries 228
7.2.5 Ply correlation 230
7.3 Ply stratigraphy of the Bowmans Deposit 231
7.3.1 C Seam 233
7.3.2 B3 Seam 235
7.3.3 B1 Seam 236
7.3.4 Ply boundaries 237
7.3.5 Ply correlation 239
7.4 Facies occurrence and distribution 239
7.4.1 Facies I 241
7.4.2 Facies II 244
7.4.3 Facies III 245
7.4.4 Facies IV 245
7.4.5 Local palaeoenvironmental inferences 246
7.5 Evolutionary patterns in local coal-forming environments and depositional models 248
7.5.1 Lochiel Deposit 248
7.5.2 Bowmans Deposit 251
7.5.3 Discussion 253
7.6 Summary 258

**8 HYDROCARBON BIOMARKERS AND THEIR DISTRIBUTION WITHIN FACIES** **261**

8.1 Compound suite, occurrence and characteristics 261
8.1.1 Normal alkanes 262
8.1.2 Sesquiterpenoids 263
8.1.3 Diterpenoids 266
8.1.4 Intact terrigenous triterpenoids 271
8.1.5 A-Ring contracted triterpenoids 272
8.1.6 Des-A triterpenoids 274
8.1.7 Hopanoids 276

8.1.8 Steroids 279
8.2 Distribution within facies and deposit 280
8.2.1 Normal alkanes 280
8.2.2 Sesquiterpenoids 281
8.2.3 Diterpenoids 283
8.2.4 Regular terrigenous triterpenoids 285
8.2.5 A-Ring contracted triterpenoids 286
8.2.6 Des-A triterpenoids 286
8.2.7 Hopanoids 287
8.2.8 Steroids 289
8.2.9 Biomarker distribution summary 289
8.3 Palaeoenvironmental implications 292
8.3.1 Comparative evaluation 292
8.3.2 Facies and local palaeoenvironments 295
8.3.3 Regional setting 296
8.4 Significance for brown coal biomarker studies 297
8.4.1 Preservation of A-ring-contracted and des-A triterpenoids 297
8.4.2 Unusual distribution of 22R-17α(H),21ß(H)-homohopane 297
8.4.3 Other issues 298
8.5 Summary 298

**9 QUARTZ, KAOLINITE AND SULPHUR DISTRIBUTION 301**

9.1 Crystalline mineral species and occurrence 301
9.2 Quartz and kaolinite distribution 302
9.2.1 Gross seam abundances 303
9.2.2 Lateral variations within Lochiel seams 306
9.2.3 Lateral variations within Bowmans seams 310
9.2.4 Vertical distribution within seams 314
9.2.5 Facies associations 316
9.3 Implications of quartz and kaolinite distribution for palaeoenvironmental evaluation 320
9.3.1 Regional setting 320
9.3.2 Deposit-specific conditions 321
9.3.3 Local depositional environment 323
9.3.4 Other inferences 324
9.4 Sulphur 325
9.4.1 Abundance and distribution 325
9.4.2 Palaeoenvironmental implications 327
9.5 Summary 328

**10 SUMMARY AND IMPLICATIONS FOR PALAEOENVIRONMENTAL ASSESSMENT OF OTHER TERTIARY COALS** **331**

10.1 Coal definition and facies classification 331
10.2 Peat-forming palaeoenvironments and the origin of facies 333
10.3 Evolutionary patterns in local palaeoenvironments 336
10.4 Comparison of mire environments in the Lochiel and Bowmans sub-basins 340
10.5 Implications for future studies of brown coals 342

**BIBLIOGRAPHY** **345**

# LIST OF PLATES


| | | |
|---|---|---|
| 5.1 | Lithotype criteria; groundmass texture types | 138 |
| 5.2 | Lithotype criteria; wood particle types | 140 |
| 5.3 | Lithotype criteria; colour | 142 |
| 5.4 | Maceral criteria; cell preservation – telovitrinite types | 144 |
| 5.5 | Maceral criteria; cell preservation – liptinite | 146 |
| 5.6 | Maceral criteria; gelification | 148 |
| 5.7 | Maceral criteria; liptinite assemblage | 150 |
| 5.8 | Maceral criteria; cutinite varieties | 152 |
| 5.9 | Maceral criteria; secondary liptinite | 154 |
| 5.10 | Maceral criteria; resinite varieties | 156 |
| 5.11 | Maceral criteria; suberinite varieties | 158 |
| 5.12 | Maceral criteria; eu-ulminite "T" | 160 |
| 5.13 | Maceral criteria; microtexture "B" | 162 |
| 6.1 | Sub-facies Ia – groundmass | 200 |
| 6.2 | Sub-facies Ia – tissue | 202 |
| 6.3 | Sub-facies Ib | 204 |
| 6.4 | Sub-facies Ic | 206 |
| 6.5 | Sub-facies IIa | 208 |
| 6.6 | Sub-facies IIb | 210 |
| 6.7 | Facies III – low mineral | 212 |
| 6.8 | Facies III – high mineral | 214 |
| 6.9 | Sub-facies IVa | 216 |

# LIST OF TABLES


| | | |
|---|---|---|
| 2.1 | Modification processes of organic matter | 11 |
| 2.2 | Coal maceral classification | 12 |
| 2.3 | Correlations reported between clastic lithofacies and adjacent coal facies | 16 |
| 2.4 | Maceral indices applied for palaeoenvironmental evaluation | 20 |
| 2.5 | Brown coal differentiation systems | 27 |
| 2.6 | Biomarker groups and major compounds detected in brown coals | 32 |
| 2.7 | Phases and types of coal mineralisation | 37 |
| 2.8 | Latrobe Valley lithotypes | 43 |
| 3.1 | Supporting information on analytical procedures presented in appendices | 45 |
| 3.2 | Lithotype logging summary | 47 |
| 3.3 | Sampling and testing summary | 48 |
| 3.4 | Point count data summary | 54 |
| 3.5 | Maceral indices | 56 |
| 3.6 | GC-MS evaluation summary | 57 |
| 3.7 | Ions monitored for biomarker evaluation | 58 |
| 3.8 | Coal chemistry sample summary | 59 |
| 3.9 | Standard procedures used for chemical testing | 60 |
| 4.1 | Rank assessment and classification parameters | 75 |
| 4.2 | Seam boundary characteristics in the Bowmans Deposit | 84 |
| 4.3 | Seam boundary characteristics in the Lochiel Deposit | 91 |
| 4.4 | Comparison of seam attributes across deposits | 101 |
| 5.1 | Groundmass texture types | 107 |
| 5.2 | Wood particle type categories | 108 |
| 5.3 | Wood abundance categories | 108 |
| 5.4 | Maceral parameters | 112 |
| 5.5 | Summary of lithotype criteria | 126 |
| 5.6 | Coal lithotypes defined from macroscopic evaluation | 127 |
| 5.7 | Summary of maceral parameters | 128 |
| 5.8 | Coal types identified from micropetrographic evaluation | 129 |
| 5.9 | Relationships between maceral and lithotype characteristics | 131 |
| 5.10 | Comparison of coal types | 132 |
| 5.11 | Coal facies summary showing key maceral and lithotype criteria | 134 |
| 5.12 | Comparison of brown coals in the St. Vincent Basin and Latrobe Valley | 135 |

| | | |
|---|---|---|
| 6.1 | Facies classification system | 166 |
| 6.2 | Lithotype and maceral properties of facies and sub-facies | 167 |
| 6.3 | Key petrographic characteristics of the sub-facies IIa varieties | 181 |
| 6.4 | Petrographic variations within facies IV | 185 |
| 6.5 | Coal facies and their interpreted palaeoenvironments | 198 |
| 7.1 | Ply stratigraphy of the Lochiel Deposit | 220 |
| 7.2 | Ply boundary characteristics in the Lochiel Deposit | 229 |
| 7.3 | Ply stratigraphy of the Bowmans Deposit | 231 |
| 7.4 | Ply boundary characteristics in the Bowmans Deposit | 237 |
| 7.5 | Facies and sub-facies distribution by seam and deposit | 241 |
| 7.6 | Inter-deposit comparison of facies architecture | 258 |
| 8.1 | CPI summary by deposit | 262 |
| 8.2 | Major sesquiterpenoids | 265 |
| 8.3 | Major diterpenoids | 269 |
| 8.4 | Major possible A-ring contracted triterpenes | 274 |
| 8.5 | Major des-A triterpenoids | 275 |
| 8.6 | Major hopanoids | 278 |
| 8.7 | RCI of *n*-alkanes by facies and deposit | 280 |
| 8.8 | Average RCI of major sesquiterpenoids by facies and deposit | 281 |
| 8.9 | Comparison of average RCI values for sesquiterpenoid sub-groups in facies I coals at Bowmans with those of an anomalously rich sample | 282 |
| 8.10 | Average RCI for major diterpenoids by facies and deposit | 283 |
| 8.11 | Comparison of average RCI values for selected diterpenoid sub-groups in sub-facies Ib coals with that of an anomalously rich sample | 285 |
| 8.12 | Average RCI for regular terrigenous triterpenoids by facies and deposit | 285 |
| 8.13 | Average RCI for A-ring contracted triterpenoids by facies and deposit | 286 |
| 8.14 | Average RCI for des-A triterpenoids by facies and deposit | 287 |
| 8.15 | Average RCI of major hopanoids by facies and deposit | 287 |
| 8.16 | Variation of 22R-17α(H),21ß(H)-homohopane/hop-17(21)-ene ratio with facies and deposit | 288 |
| 8.17 | Source affinity of coal facies based on the relative abundances of gymnosperm (conifer), angiosperm and bacterial biomarkers | 294 |

| | | |
|---|---|---|
| 9.1 | Mineralogy of Lochiel and Bowmans coals | 301 |
| 9.2 | Average mineral contents and ash composition for each seam | 303 |
| 9.3 | Estimated mineral abundance with facies and deposit | 316 |
| 9.4 | Total sulphur abundance in the Lochiel and Bowmans Deposits | 325 |
| 9.5 | Variation of average total sulphur content with facies and deposit | 327 |

# LIST OF FIGURES


| | | |
|---|---|---|
| 1.1 | Locality plan and major geological features | 2 |
| 2.1 | Mire types hosting organic matter accumulation | 8 |
| 2.2 | Peat variation with groundwater level | 14 |
| 2.3 | Upward-lightening lithotype sequences in Latrobe Valley brown coals | 18 |
| 2.4 | Generalised seam characteristics with depositional setting | 22 |
| 2.5 | Brown coal lithotype models | 24 |
| 2.6 | Carbon skeletons of selected brown coal biomarkers | 30 |
| 2.7 | Southern Australian brown coal deposits | 41 |
| 3.1 | Research project methodology | 46 |
| 3.2 | Investigation sites in the Lochiel Deposit | 50 |
| 3.3 | Investigation sites in the Bowmans Deposit | 51 |
| 4.1 | Geology of the St. Vincent Basin | 64 |
| 4.2 | Coalfields of the northern St. Vincent Basin | 66 |
| 4.3 | North-south cross section through the Lochiel and Bowmans Deposits | 67 |
| 4.4 | Correlation chart for Tertiary strata in the St. Vincent Basin | 68 |
| 4.5 | Stratigraphy of the Bowmans and Lochiel Deposits | 71 |
| 4.6 | Coal stratigraphy of the Bowmans Deposit | 77 |
| 4.7 | Seam occurrence and characteristics in the Bowmans Deposit | 78 |
| 4.8 | Representative cross sections through the Bowmans Deposit | 79 |
| 4.9 | Seam variability in the Bowmans Deposit | 81 |
| 4.10 | Seam boundaries in the Bowmans Deposit | 83 |
| 4.11 | B1 Seam roof variation in the Bowmans Trail Pit | 85 |
| 4.12 | Coal stratigraphy of the Lochiel Deposit | 86 |
| 4.13 | Seam occurrence and characteristics in the Lochiel Deposit | 87 |
| 4.14 | Representative cross sections through the Lochiel Deposit | 88 |
| 4.15 | Irregular F Seam roof at a bulk sampling site in the Lochiel Deposit | 90 |
| 4.16 | Seam boundaries in the Lochiel Deposit | 92 |
| 4.17 | Lateral variation in ash and mineral contents with respect to seam margins | 94 |
| 4.18 | Palaeogeographic reconstructions of the Bowmans and Lochiel Deposits | 97 |
| 5.1 | Frequency distributions of maceral group content | 113 |
| 5.2 | Maceral characteristics represented on ternary diagrams, and key maceral indices | 114 |
| 5.3 | Frequency distributions of tissue preservation indices | 118 |

| | | |
|---|---|---|
| 5.4 | Frequency distributions of gelification indices | 121 |
| 5.5 | Frequency distributions of liptinite composition indices | 124 |
| 5.6 | Colour index comparison | 136 |
| 6.1 | Maceral characteristics of facies I coals | 169 |
| 6.2 | Facies I maceral variations | 170 |
| 6.3 | Lithotype and maceral trends in facies I coals | 171 |
| 6.4 | Maceral characteristics of facies II coals | 177 |
| 6.5 | Lithotype and maceral trends in facies II coals | 178 |
| 6.6 | Maceral variations within facies II coals | 179 |
| 6.7 | Petrographic characteristics of sub-facies IIa varieties | 180 |
| 6.8 | Maceral characteristics of facies III coals | 184 |
| 6.9 | Maceral characteristics of facies IV coals | 186 |
| 6.10 | Micropetrographic summary of the facies | 189 |
| 6.11 | Interpreted palaeoenvironments of the coal facies | 190 |
| 6.12 | Ground fire leading to sub-facies IVa formation | 196 |
| 7.1 | Ply stratigraphy of the Lochiel Deposit | 221 |
| 7.2 | Lochiel Deposit H Seam ply isopachs | 222 |
| 7.3 | Lochiel Deposit G Seam ply isopachs | 224 |
| 7.4 | Lochiel Deposit F Seam ply isopachs | 226 |
| 7.5 | Ply correlation through the Lochiel Deposit | 227 |
| 7.6 | Irregular nature of F4 ply | 228 |
| 7.7 | Ply boundary characteristics in the Lochiel Deposit | 229 |
| 7.8 | Ply stratigraphy of the Bowmans Deposit | 232 |
| 7.9 | Ply correlation through the Bowmans Deposit | 234 |
| 7.10 | Ply boundaries characteristics in the Bowmans Deposit | 238 |
| 7.11 | Facies distribution by seams and deposit | 240 |
| 7.12 | Deposit comparison of facies diversity and abundance | 243 |
| 7.13 | Major coal forming stages in the Lochiel Deposit | 249 |
| 7.14 | Major coal forming stages in the Bowmans Deposit | 252 |
| 7.15 | Deposit comparison of maceral characteristics | 256 |
| 7.16 | Deposit comparison of ply stratigraphy | 257 |
| 8.1 | Compound classes in the aliphatic fraction | 261 |
| 8.2 | Representative normal alkane distribution | 262 |
| 8.3 | Representative sesquiterpenoid distribution | 263 |
| 8.4 | Anomalous sesquiterpenoid occurrence | 266 |
| 8.5 | Representative diterpenoid distribution | 267 |
| 8.6 | Anomalous diterpenoid occurrence | 270 |
| 8.7 | Representative intact terrigenous triterpenoid distribution | 272 |

| | | |
|---|---|---|
| 8.8 | Representative A-ring contracted triterpenoid distribution | 273 |
| 8.9 | Representative des-A triterpenoid distribution | 275 |
| 8.10 | Representative hopanoid distribution | 277 |
| 8.11 | Representative steroid distribution | 279 |
| 8.12 | Relationship between sesquiterpenoid abundance and resinite content | 283 |
| 8.13 | Relationship between diterpenoid abundance, resinite and telovitrinite | 284 |
| 8.14 | Relationship between the two major hopanoids | 288 |
| 8.15 | Relationships with and between gymnosperm and angiosperm biomarker groups | 290 |
| 8.16 | Variation of mean biomarker abundances with facies and deposit | 291 |
| 8.17 | Relationship between the dominant hopanoids and total *n*-alkane abundance | 293 |
| 8.18 | Angiosperm and gymnosperm input relative to bacterial contribution | 294 |
| 9.1 | Ash composition and estimated quartz and kaolinite content by seam and deposit | 304 |
| 9.2 | Quartz-kaolinite cross plots by seam | 305 |
| 9.3 | H Seam quartz and kaolinite distribution through the Lochiel Deposit | 306 |
| 9.4 | G Seam quartz and kaolinite distribution through the Lochiel Deposit | 308 |
| 9.5 | F Seam quartz and kaolinite distribution through the Lochiel Deposit | 309 |
| 9.6 | C Seam quartz and kaolinite distribution through the Bowmans Deposit | 311 |
| 9.7 | B3 Seam quartz and kaolinite distribution through the Bowmans Deposit | 312 |
| 9.8 | B1 Seam quartz and kaolinite distribution through the Bowmans Deposit | 313 |
| 9.9 | Vertical mineral distribution | 315 |
| 9.10 | Mineral variations with facies | 317 |
| 9.11 | Facies to mineral relationships | 318 |
| 9.12 | Lateral mineral variability | 319 |
| 9.13 | Vertical sulphur gradients | 326 |

# LIST OF APPENDICES


**APPENDIX A SAMPLING AND TESTING REGISTER**

**APPENDIX B BOREHOLE LITHOTYPE LOGS**

**APPENDIX C MACERAL ANALYSIS**

C1 Sub-maceral definition
C2 Maceral point count data

**APPENDIX D BIOMARKER EVALUATION**

D1 Compound characteristics and identification
D2 Representative mass spectra of major compounds
D3 RCI methodology, GC-MS peak measurements and RCI values

**APPENDIX E CHEMICAL AND MINERAL ANALYSIS**

E1 Quartz and kaolinite estimation methodology
E2 Analytical data from coal chemistry
E3 Quartz and kaolinite mineral estimates

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AS | Australian Standard |
| ASTM | American Society for Testing and Materials Standards |
| CPI | Carbon preference index |
| DCM | Dichloromethane |
| EOM | Extractable organic matter |
| ETSA | Electricity Trust of South Australia |
| GC-MS | Gas Chromatography – Mass Spectrometry |
| GI | Gelification index |
| ICCP | International Committee for Coal and Organic Petrology |
| LAI | Liptinite alteration index |
| LEI | Liptinite environmental index |
| LPI | Liptinite preservation index |
| MTI | Massive telovitrinite index |
| PIRSA | Department of Primary Industries and Resources South Australia |
| RCI | Relative concentration index |
| RIC | Reconstructed ion chromatogram |
| SECV | State Electricity Commission of Victoria |
| SEM/EDS | Scanning electron microscopy with energy dispersive x-ray spectrography |
| SENRAC | State Energy Research Advisory Committee |
| TPI | Tissue preservation index |
| VPI | Vitrinite preservation index |
| XRD | X-ray diffraction |

## ACKNOWLEDGEMENTS

I would like to acknowledge several individuals and groups that have made this project possible. There are those who have suffered and endured, those who have provided influence and inspiration and those who have assisted in a myriad of technical aspects of the study.

I must first acknowledge that select group who have endured the project and provided ongoing support. Foremost amongst this group is my wife Sue who deserves my eternal gratitude for her patience, support, belief and the numerous sacrifices she has made to enable its completion. To my children Lauren, Heather, Stephanie and John thank you for your understanding, support and motivation. I would also like to express my deepest thanks and appreciation to Chud, Beth and Sue for their inspiration.

From the technical viewpoint there are numerous individuals and organisations that I would like to thank. Firstly, the University of Adelaide is acknowledged for their support and in particular my supervisors, Associate Professors David McKirdy and Victor Gostin and at the project inception Professor Larry Frakes. I would also like to especially thank Associate Professor McKirdy for his critical evaluation of the manuscript.

I am greatly indebted to the former Electricity Trust of South Australia, and in particular the Coal Resources Branch, for their permission to undertake this project and for access to a variety of data, including borehole cores, analytical data, survey information and lithological logs. The support of the State Energy Research Authority is also gratefully acknowledged. My thanks to Mick O'Brien, Dr Eric Linder and Alistair Muir for their support, Dr Andrew Kremor for the many discussions and the staff from the Torrens Island Power Station Laboratory for chemical analysis. I would also particularly would like to thank John Vingelis and Frank Myska for their assistance and advice on the intricacies of coal chemistry and Keith Plastow and Ken Wigglesworth for their useful suggestions.

Personnel from the former State Electricity Commission of Victoria were very encouraging and helpful during the project's infancy. In particular Miles George provided extensive tutorage in brown coal petrology. My thanks to Guy Holdgate, Paul Bolger, Rod Webster and Colin Barton for their helpful suggestions in developing the research direction, discussions on the Latrobe Valley coals and the assorted research information provided.

My thanks to Dr Allen Chaffee of Monash University, for his very useful advice regarding brown coal biomarkers and procedures for their evaluation. I would also like to thank Bernd Michaelsen for inspiration and assistance with organic geochemistry.

Technical staff at the University of Adelaide provided critical assistance and advice including Evert Bleys with regard to the coal petrology microscope and Wayne Mussared for grain mount preparation and polishing. I would also like to acknowledge the assistance of Russell Aspland and Valerie Dancis with drafting.

Finally my thanks to those who have undertaken co-operative research during the course of the project including; Dave Readett, Keith Quast, James Manuel, Dr. Andrew Rowett, Dr. David Christophel and Liliana Stoian.

# ABSTRACT

The Middle Eocene to Early Oligocene Bowmans and Lochiel Coal Deposits of the northern St. Vincent Basin, South Australia, have been studied to elucidate their depositional environments. These coals occur within predominantly fluvio-lacustrine transgressive system tract sequences that formed during the initial phase of basin infill.

Eight genetically distinct, mostly vitrinite-dominated coal types were recognised and four facies were defined in line with varying levels of biomechanical degradation and changes in precursor organic matter. Facies I coals form thick, commonly wood-rich plies and are characterised by high terrestrial liptinite contents, low gelification, elevated concentrations of gymnosperm and angiosperm biomarkers, and a quartziferous mineralogy. Primarily autochthonous accumulation in mixed angiosperm-gymnosperm forest swamps is inferred. Facies II coals tend to be laterally extensive and are distinguished by low wood contents with abundant groundmass telovitrinite, high tissue preservation, a mixed terrestrial-aquatic liptinite assemblage, low levels of plant-derived terpenoids and a kaolinitic mineralogy. Autochthonous accumulation under elevated groundwater conditions from water-tolerant species in subaquatic marshlands is postulated. Facies III coals are highly gelified, have relatively low terrestrial terpenoid contents, exhibit some sapropelic characteristics and contain abundant mineral matter. Typically thin with limited lateral consistency, these coals are products of the accumulation of fine allochthonous and aquatic organic matter in an open water environment. Facies IV coals have an erratic distribution and comprise physically altered, friable and macrinite-dominated lithotypes. They are interpreted to be products of weathering and peat combustion, respectively.

The aforementioned facies are unevenly distributed and their stratigraphic succession highlights evolutionary changes in local palaeoenvironments. Within individual seams the transition from subaquatic to topogenous forest swamps and ultimately ombrogenous conditions is most common. However, over the coal sequence as a whole, conditions evolved from exclusively terrestrial through mixed terrestrial and subaquatic to open water. Also detected were multiple rapid reversals of the water table, especially higher in the sequence, and cyclic patterns reflecting a brief basal subaquatic phase prior to the onset of sustained terrestrial conditions. These patterns suggest a fluctuating, although progressively rising, water table and, and a balance between accommodation and accumulation.

Peat in the Lochiel Deposit accumulated within a restricted fault-bound sub-basin strongly influenced by local tectonics and a fluctuating hydrological regime, resulting in diverse, well-banded coals, a relatively fixed depocentre, and a well-defined facies succession. In contrast,

extensive peat accumulation within inter-channel floodplain settings is interpreted for the Bowmans Deposit. Here more stable groundwater conditions and autosedimentological mechanisms controlled the peat characteristics, giving rise to low facies diversity, a weakly developed facies succession, and variable seam thickness and extent. Assorted marine indicators suggest a slightly more distal setting for the Lochiel Deposit.

# 1 INTRODUCTION

## 1.1 BACKGROUND

Exploration drilling for brown coal has been undertaken intermittently around the head of Gulf St. Vincent, South Australia, since the 1920's. However, in response to the perceived need for additional local reserves of steaming coal to fuel base-load power generation, work intensified between 1975 and 1989 leading to the delineation by the former Electricity Trust of South Australia (ETSA) of major coal resources in the vicinity of Bowmans and Lochiel, located approximately 100 and 130 km north of Adelaide, respectively (Figure 1.1). The former represents an extension of the previously known Tertiary brown coal occurrences in the area, while the latter is another discrete deposit albeit of similar age and rank. The author was involved in coalfield exploration and resource assessment throughout this period, as part of a broad research effort to evaluate the suitability of these two deposits for power generation.

Combustion testing of these northern St. Vincent Basin coals identified several potentially deleterious materials (e.g. sulphur, sodium and chlorine) and highlighted the importance of coal quality to their successful utilisation. Accordingly, detailed assessment of individual coal seams and their characteristics was initiated. Properties were found to vary significantly, both within and between seams, suggesting the occurrence of multiple coal lithotypes that accumulated in a variety of depositional settings. From this background the current research project was conceived, with the aim of evaluating in detail Tertiary coal-forming palaeoenvironments in southeastern Australia and the manner in which coal type changes in response to assorted depositional factors, using the Lochiel and Bowmans Deposits as examples.

A multi-faceted investigation of the Lochiel and Bowmans coal deposits was undertaken in which the major research components were petrographic determination of lithotype and maceral composition; assessment of facies distribution; biomarker characterisation of coal facies; and evaluation of the syngenetic mineral matter. Using the resulting data, coals were differentiated and classified according to key attributes such as the nature of their primary organic material, the extent of its biological alteration and the amount and nature of the associated mineral constituents. Careful synthesis of maceral, lithotype, biomarker and mineralogical data allowed palaeoenvironmental reconstruction of each deposit. Other supporting data from coalfield resource investigations and co-operative palaeobotanical and mineralogical evaluations were also collated and integrated to assist this process.

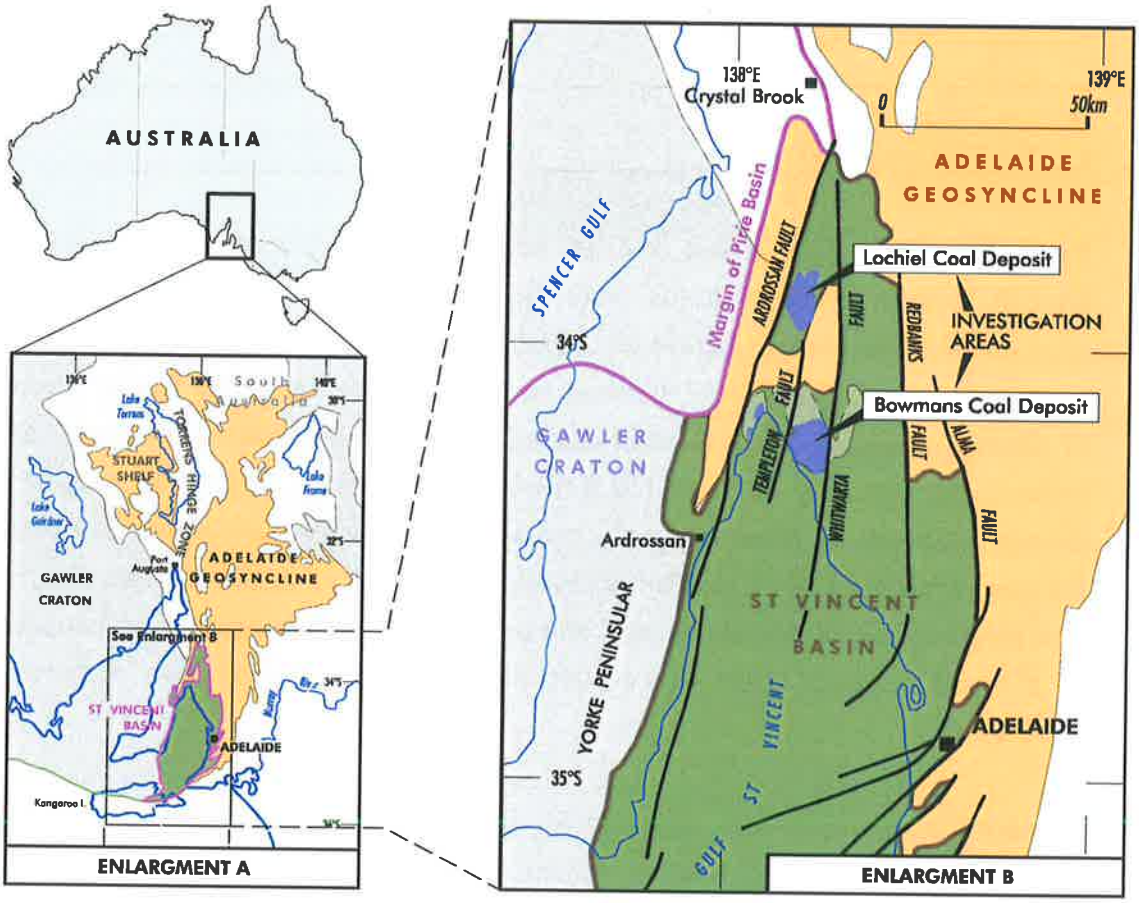



Figure 1.1 Locality plan and major geological features

## 1.2 OBJECTIVES

### 1.2.1 Project aims

The overriding aims of the research were to elucidate the depositional environments in which the Tertiary coals of South Australia accumulated and to evaluate their stratigraphic variation in response to local and regional palaeoenvironmental factors. The hitherto poorly documented coals of the Lochiel and Bowmans Deposits, products of Middle Eocene to Early Oligocene peat accumulation, were chosen as the main vehicles for this research.

An interdisciplinary research program such as this was made possible through the author's privileged access to core samples and coal seam exposures during exploration drilling and trial pit excavation, and to a diverse range of analytical and borehole data. The resulting extensive data suite is uncommon in Tertiary coal investigations and provides an optimum basis for palaeoenvironmental evaluation. Consequently, the thesis also aims to make a

significant contribution to worldwide coal research and, in particular, to assist in the understanding and prediction of coal characteristics.

### 1.2.2 Specific research objectives

The research outlined herein addresses problems associated with the definition of coal type in low-rank deposits, the evaluation of local peat forming palaeoenvironments, the assessment of spatial and temporal changes in depositional conditions and elucidation of the regional sedimentary setting of the northern St. Vincent Basin.

The five specific objectives of the research are elaborated:

**Objective 1: To develop genetically based coal differentiation criteria, identify coal types and assign them to facies groups**

This project represents the first in-depth evaluation of coals within the northern St. Vincent Basin coalfield. In the absence of an established system for differentiating coal types, development of appropriate lithotype and maceral criteria was required as the basis for a genetic system of facies identification and classification. Facies identification using these criteria, formed the basis for correlation, spatial evaluation and palaeoenvironmental assessment throughout the research project.

**Objective 2: To evaluate and integrate the lithotype, petrographic, biomarker, mineral and spatial characteristics of each facies and to infer its likely local palaeoenvironment**

Brown coals exhibit a wide compositional diversity, requiring a multidisciplinary approach to their evaluation. The lithotype and micropetrographic characteristics of the coals together with their aliphatic hydrocarbon biomarker distributions facilitated assessment of the precursor plant remains and the biogeochemical conditions under which they accumulated. Syngenetic mineral composition provided information on the nature of overbank incursion and possible swamp conditions, while facies occurrence and distribution enabled evaluation of the extent and duration of the various environmental settings. While not individually unique in prior investigations of brown coals, compilations of all such data are rarely available for the same deposit.

**Objective 3: To evaluate facies architecture through the Lochiel and Bowmans coal-bearing sequences and assess the evolutionary development of peat forming conditions**

The manner in which coal varieties are distributed within seams and throughout the coal sequence as a whole reflects the changing nature of local peat forming palaeoenvironments over time. The distribution and thickness of different facies facilitated assessment of the intraseam and interseam evolution of coal forming conditions. Furthermore, this aspect of the research allowed refinement of environmental reconstructions based on petrography alone and evaluation of the key factors influencing peat accumulation.

**Objective 4: To compare and contrast coal attributes for the Lochiel and Bowmans Deposits and infer regional depositional settings for coal formation in the northern St. Vincent Basin**

Although coal is widespread throughout the northern portion of the St. Vincent Basin, the Lochiel and Bowmans Deposits represent discrete accumulations separated by a ridge of pre-Tertiary bedrock. Assessment of the stratigraphy, structure and more particularly the seam attributes in each deposit facilitated an overview of likely sedimentary environments and the broad pattern of coal formation over time. Findings from this facet of the research were integrated with the palaeoenvironmental and facies analyses of each deposit to construct a regional picture of Tertiary peat accumulation and its relationships to the tectonic, sedimentary and eustatic history of the northern St. Vincent Basin.

**Objective 5: Through detailed investigation of the Lochiel and Bowmans Deposits, to contribute to the broader understanding of the nature and origin of Tertiary coals throughout southern Australia**

This study seeks to advance our knowledge and understanding of the Tertiary coals of southern Australia employing a novel combination of petrographic, sedimentological and geochemical (both organic and inorganic) techniques. The parallel evaluation of two nearby deposits has the potential to reveal those features that are due to subtle, local changes in the regional setting.

## 1.3 RESEARCH PROGRAM

A phased, multidisciplinary research program was developed that commenced with a broad appraisal of sedimentary settings for the Bowmans and Lochiel areas. Subsequent

investigations became progressively focused on the definition and detailed assessment of coal types, with the latter forming the bulk of the research program.

Data gathering involved lithotype, micropetrographic, biomarker and inorganic geochemical investigations, combined with sedimentology and, where possible, co-operative mineral, palaeobotanical and palynological studies. The project thereby aimed to provide a diverse data set on which a comprehensive evaluation of local and regional coal-forming conditions could be based.

Petrographic analysis using reflected white-light and fluorescence-mode microscopy, together with lithotype logging were the primary investigative tools that provided key data for the differentiation, identification and classification of coal facies and their palaeoenvironmental interpretation. This information was also applied to the evaluation of the facies architecture within and between seams. Organic geochemical and mineralogical studies provided additional information that allowed further refinement of palaeoenvironmental inferences. In particular, the former facilitated assessment of the nature and relative contributions of bacterial and higher plant sources to each major facies and the two deposits, while the latter was used to evaluate the interrelationship between contemporary organic and clastic sedimentation throughout the period of coal formation.

Collation of pre-existing background data such as lithological borehole logs, geophysical logs and chemical testing, obtained during routine coalfield exploration programs was also undertaken. This supplemented the analytical data acquired during the current project (focusing on coal varieties and local depositional environments). The result was a regional evaluation of seam characteristics and the interrelationship between coal and clastic sediments through the coal-forming period. Findings from some co-operative investigations were also incorporated where appropriate.

## 1.4 THESIS ORGANISATION

The thesis is organised into ten chapters, with the current chapter providing an introduction to the project and outlining the objectives and scope of the investigation. Chapter 2 is a review of the literature on brown coals that is relevant to the research presented herein, while Chapter 3 describes the data collection and evaluation methodology. Specific discussion of the Lochiel and Bowmans Deposits and their coals commences in Chapter 4 with a summary of the regional geology and the nature of coal occurrence in each deposit.

The remainder of the thesis parallels the main research directions followed during the study. Chapters 5 to 7 address the definition and classification of coal facies and discuss their

petrographic and spatial attributes. These findings are used to develop palaeoenvironmental interpretations for each of the facies, evaluate facies sequences and infer the nature of peat accumulation over time in each deposit. The biomarker distributions of individual facies are presented in Chapter 8 and their syngenetic mineral and sulphur contents are reviewed in Chapter 9. Together these data sets are used to evaluate source material, swamp conditions and assess the nature of contemporary clastic sedimentation. At the conclusion of each of these chapters a concise summary detailing the principal findings and their significance is presented.

A synthesis of the local and regional coal-forming palaeoenvironments of the Bowmans and Lochiel Deposits is presented in Chapter 10. A suite of appendices collating relevant data collected during the study accompanies the thesis (Appendices A to E).

# 2 COAL FORMATION, DEPOSITIONAL MODELS AND THE CHARACTERISTICS OF TERTIARY BROWN COALS

Literature pertinent to the research undertaken in this project resides in a wide variety of sub-disciplines including sedimentology, coal petrology, palaeobotany, geomicrobiology and geochemistry (both organic and inorganic). This chapter is an overview of the literature on the geological conditions necessary for peat formation, the key factors influencing coal type (as expressed in maceral and mineral constituents), and recent developments in the study of brown-coal biomarkers. Systems for the differentiation and classification of brown coals are also reviewed and Tertiary deposits along the southern portion of the Australia continent considered with respect to their tectonic, depositional and climatic settings.

## 2.1 PROCESSES AND ENVIRONMENTS OF COAL FORMATION

### 2.1.1 Accumulation of organic matter

The initiation and maintenance of peat-forming conditions is a relatively uncommon event and requires the appropriate interaction of biological, climatic and geological factors. Such conditions reflect an excess of local plant productivity over decomposition, indicating a degree of ecological imbalance. The latter may be due to retardation of microbial activity (leading to reduced consumption of organic matter) or high productivity, or a combination of both (Moore, 1987, 1989, 1995; Diessel *et al.*, 2000).

Coals originate from vegetable matter accumulated in wet, swampy, mire[1] settings that have subsequently undergone compaction and gelification. Plant matter typically accumulates by normal sedimentary processes such as falling into, or being transported to a peat bog or mire, although root or rhizome growth into peat may also occur (Cohen *et al.*, 1987; Moore, 1995; Figure 2.1). Apart from some minor transport and re-deposition, organic matter is predominantly autochthonous, with allochthonous constituents normally present in small to moderate amounts. As a consequence of the various accumulation processes, adjacent constituents may reflect differing degrees of transformation.

[1] Mire is used as a general term in this thesis to describe peat forming ecosystems (Moore,1987, 1989).

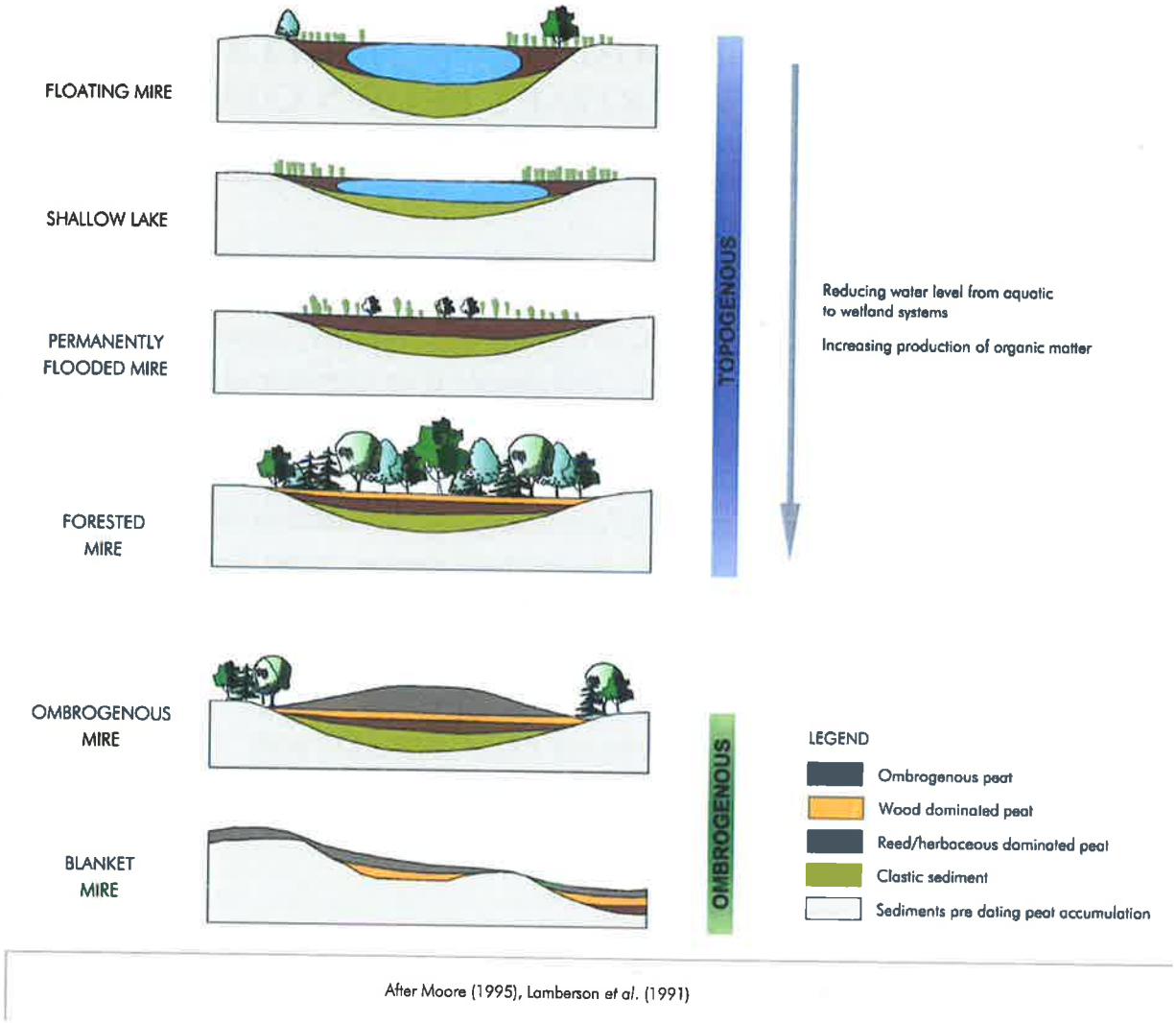



Figure 2.1 Mire types hosting organic matter accumulation

Peat deposition rates vary with climate and flora, with estimates ranging from 0.03 to 5 mm per year, with highest accumulation rates in tropical settings (Stach *et al.*, 1982; Hager, 1993; Holdgate *et al.*, 1995; Diessel *et. al.*, 2000). Volume loss due to compression is considerable and varies depending on coal type, with high-moisture reed peats compressing more readily than wood-rich, forest peats. An overall compaction ratio of 2.5:1 was suggested for the peat to brown coal stage by Holdgate *et al.* (1995).

### 2.1.2 Requirements for peat formation

Critical requirements of peat formation include sufficient standing water to retard oxidation and bacterial decay, a substantial growth of vegetation, minimal inorganic sedimentation and slow and steady subsidence, or relative subsidence in the form of rising groundwater (Cohen *et al.*, 1987; Fielding, 1988; Moore, 1989, 1995; Teichmuller, 1989; Taylor *et al.*, 1998).

These conditions may exist in a wide variety of climates and settings, providing suitable precursor plants and hydrological conditions exist (Cohen *et al.*, 1987; Diessel, 1992).

Groundwater level is of fundamental importance, as preservation of vegetable matter is only possible where protected from oxidation and decay. Stagnant water provides an efficient air lock and facilitates preservation (Moore, 1989). However, a delicate balance exists between areas that are topographically low (and easily inundated by sediment influx) and those too high to permit accumulation of organic matter (resulting in subaerial exposure and degradation). In ombrogenous environments, i.e. peat formation above the groundwater table with water sourced through rainfall and/or capillary action, (Diessel, 1992; Taylor *et al.*, 1998) degradation of organics may be retarded sufficiently to allow accumulation by a combination of high precipitation, low evaporation, acidic conditions and capillary groundwater action (Anderson and Mackay, 1990).

A ready supply of vegetation is necessary to provide source material for peat accumulation. Vegetation types vary significantly and depend principally on groundwater depth, climate and swamp conditions. Temporal variations also exist reflecting the evolutionary state of the flora at the time of coal formation (Shearer *et al.*, 1995; Taylor *et al.*, 1998).

An absence, or limitation of clastic sedimentation is required to enable sufficient vegetable matter to accumulate without inundation or dilution by mineral matter. This requirement may be satisfied where plants around the periphery of the swamp act as a sediment trap, settings are protected from active sedimentation by their interchannel or distal positions, sediment supply is limited, or ombrogenous conditions develop (Flores, 1993; Taylor *et al.*, 1998; Michaelson and Henderson, 2000). Leaching is another means of reducing the mineral component of peat (Cohen *et al.*, 1987).

For continued peat accumulation, subsidence at rates broadly proportional to peat formation is necessary (Teichmuller, 1989). If these conditions do not exist then coal formation will be terminated due to either non-preservation or drowning of swamp vegetation, from insufficient or excessive subsidence, respectively.

### 2.1.3 Peat-forming sedimentary environments

Peat may form in assorted sedimentary environments, ranging from paralic swamps to river lowlands and various inland lacustrine settings (McCabe, 1987; Flores, 1989; Teichmuller, 1989; Johnson, 1995; Flores and Sykes, 1996; Taylor *et al.*, 1998; Holdgate and Clarke, 2000). Favourable environments include braid plains, alluvial valley/upper delta plain, lower

delta plain, barrier beach/strand plains and estuaries (Diessel, 1992). In large basins these may laterally coexist and supersede each other vertically.

Coastal zones offer a number of settings for peat accumulation including delta plains, back barriers and estuarine environments. On the lower delta plain thin peats may accumulate in interdistributary swamps and marshes, while coastal plains landward of barrier beaches and coast-parallel lagoons provide large areas for uninterrupted peat formation (Kalkreuth *et al.*, 1991; Diessel, 1992, Holdgate *et al.*, 2000). In the latter setting, sapropelic peats may form from lacustrine algae in deeper parts of the lagoon, prior to the establishment of brackish-tolerant vegetation. Peats may also accumulate along the shore of estuaries and tidal flats, resulting in thin and discontinuous seams (Diessel, 1992; Johnson, 1995).

Poorly drained back-swamps on the flood plain between rivers can host thick peat accumulations. Here, peat extent is related to the size and sinuosity of the river channels and channel migration (Diessel, 1992; Kolcon and Sachsenhofer, 1999). Thick, laterally extensive peats with the lowest mineral contents typically develop along the interchannel axis, while abrupt lateral thinning and splitting occurs towards the channel. Peat can also form together with coarse clastic deposits in braid plain and alluvial fan settings (Ward, 1984; Diessel, 1992; Flores and Sykes, 1996), resulting in thin to moderate seams that may be laterally extensive (Johnson, 1995).

Lacustrine related settings for peat formation range in size from large basins to small isolated lakes, where they occur peripheral to and above lacustrine sediments. In contrast to coastal and alluvial settings, coal may represent the dominant lithology within a succession comprising relatively thin clastic beds and very thick seams (Johnson, 1995). Restricted clastic input results in peat with low mineral contents and essentially stationary depocentres. Unconfined peatlands represent a further inland coal- forming setting that can overlie a variety of sediments, producing extensive mineral poor, often thick seams with very consistent profiles (Ward, 1984; Johnson, 1995; Michaelsen and Henderson, 2000).

Tectonic settings suitable for coal formation range from stable intracratonic, to active orogenic, basins. Orogenic belts and, in particular, foredeeps adjacent to convergent plate margins can host extensive coal deposits (Diessel, 1992). In this setting coals are laterally restricted and typically occur as numerous thin horizons, although thick peats may also accumulate where balances in tectonic subsidence, sediment supply and eustasy exist (Ward, 1984; Flores and Sykes, 1996). Although less mobile, passive continental margins may also host coal deposits of assorted characteristics (Holdgate and Clarke, 2000). Intracratonic locations, such as intramontane basins and consolidated basement within the continental interior (Diessel, 1992), provide broad platforms on which unconfined peatlands develop.

Within a sequence stratigraphic framework, the thickest and most extensive coals are part of transgressive systems tracts, while those in lowstand systems tracts tend to be moderately thin and discontinuous (Diessel, 1992; Holdgate *et al.*, 2000; Holz *et al.*, 2002). Thick coals may also form during regressive phases of highstand systems tracts, especially in the vicinity of the maximum flooding surface.

### 2.1.4 Coalification

The transformation of plant tissue into brown coal primarily involves a biochemical stage during which the discrete organic constituents are gelified. This process is promoted under water in an anaerobic environment by bacteria and fungi and involves intense softening and dispersion of the primary organic detritus (ICCP, 1975; Diessel, 1980, 1986; Taylor *et al.*, 1998).

Biochemical conditions vary over the course of coalification, typically ranging from aerobic environments of plant growth and death, to increasingly anoxic conditions with burial and elevated groundwater conditions (Anderson and Mackay, 1990; Table 2.1). From the peat surface to a depth of approximately 0.5 m, plant debris in initially subject to attack from fungi, aerobic bacteria and ingestion, or metabolism, by animals (Cohen *et al.*, 1987), leading to tissue breakdown and selective decomposition of the cell contents. With depth, these aerobic heterotrophs are replaced by anaerobic bacteria, which contribute to both tissue degradation and gelification (Diessel, 1980). With progressively decreasing oxygen availability in the pore network of the peat, processes change from mouldering to peatification and ultimately putrefaction (Taylor *et al.*, 1998), with peatification being the main step in preservation. At a depth of approximately 10 m, microbial life is generally terminated and coalification is further advanced by chemical changes associated with increasing temperature (Stach *et al.*, 1982). The rate of burial has a direct effect on the degree of preservation by limiting the duration of aerobic decay.

Table 2.1 Modification processes of organic matter (after Taylor *et al.*, 1998)

| Process | Oxygen Supply | Product | Coal Type |
|---|---|---|---|
| Disintegration | Aerobic | Very limited solid residue | Possible liptobiolith |
| Mouldering | Aerobic | Mould | Humic |
| Peatification | Anaerobic | Peat | Humic |
| Putrefaction | Anaerobic | Sapropel | Sapropelic, oil shale |

### 2.1.5 Factors determining coal type

Critical factors influencing coal type include the nature of source material and degree of biochemical modification (Hagemann and Hollerbach, 1980; Ward, 1984; Johnson, 1995; Moore and Shearer, 2003). Both in turn are closely related to assorted local features such as groundwater position, moor ecology and type, biochemical conditions, swamp conditions and the mode of accumulation (Dehmer, 1995; Diessel and Smyth, 1995; Wust *et al.*, 2001; Moore and Shearer, 2003). In addition, regional factors such as sedimentary and tectonic setting, climate, and the evolutionary development of the flora can also exert some influence over primary coal characteristics (Dehmer, 1995; Wust *et al.*, 2001). The precise manner in which these variables interrelate is complex and primary peat characteristics can be overprinted by secondary processes related to the degree and nature of degradation (Moore and Shearer, 2003). Coal characteristics and coal type can be described in terms of its maceral composition (Table 2.2).

Table 2.2 Coal maceral classification (AS 2856.2-1998)

| Maceral group | Maceral sub-group | Maceral |
|---|---|---|
| Vitrinite | Telovitrinite | Textinite<br>Texto-ulminite<br>Eu-ulminite<br>Telocollinite |
| | Detrovitrinite | Attrinite<br>Densinite<br>Desmocollinite |
| | Gelovitrinite | Corpogelinite<br>Porigelinite<br>Eugelinite |
| Liptinite | - | Sporinite<br>Cutinite<br>Resinite<br>Liptodetrinite<br>Alginite<br>Suberinite<br>Fluorinite<br>Exsudatinite<br>Bituminite |
| Inertinite | Telo-inertinite | Fusinite<br>Semifusinite<br>Funginite |
| | Detro-inertinite | Inertodetrinite<br>Micrinite |
| | Gelo-inertinite | Macrinite |

Local factors lead to intraseam variations in coal type and banding. In contrast, regional and time-dependent issues affect gross coal characteristics and result in gradual changes through the sequence. These are outlined below.

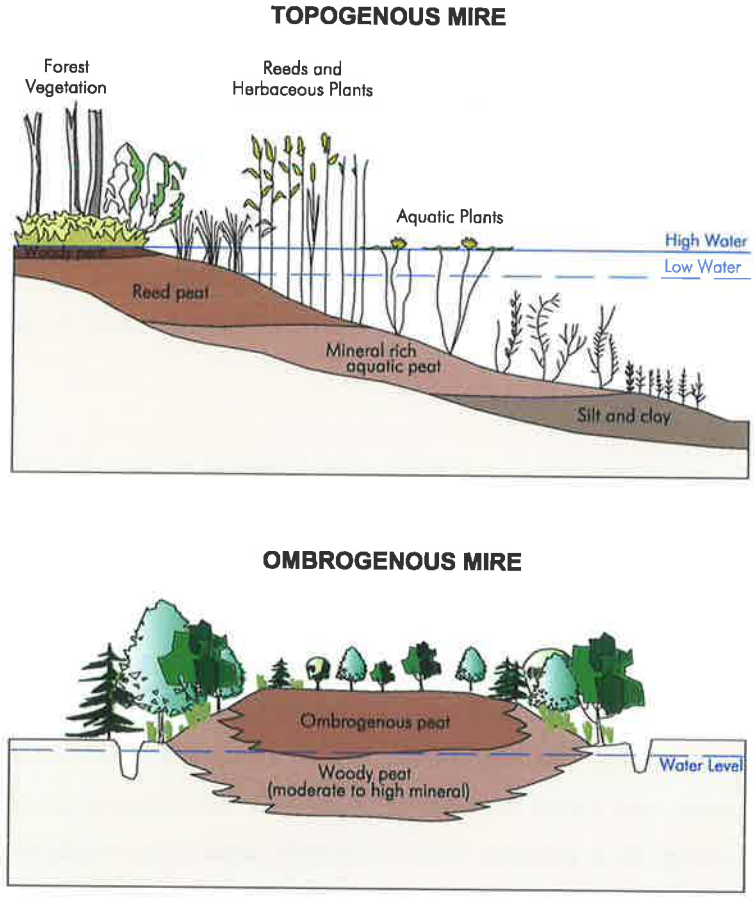
### 2.1.5.1 Local factors

***Groundwater Level***

Groundwater controls both the environment in which plants grow and the setting in which vegetable matter accumulates, thus having a fundamental influence over the type of source material and the state of its preservation (Taylor *et al.*, 1998; Moore and Shearer, 2003). Variations in hydrological conditions can lead to stratification in the seam and vertical fluctuations of 0.01 to 0.1 m are possibly sufficient to modify coal type (Ferm and Staub, 1984; Diessel, 1992).

Peat-forming swamp environments range from open water to almost dry land, with changes in water depth reflected by segregation of flora into assorted plant communities and, ultimately, by coal type. Although the wet conditions may preclude certain plants from contributing to peat deposits, many varieties do, including woody gymnosperms and angiosperms, floating and emergent herbaceous aquatics and lower plants such as mosses and algae (Cohen *et al.*, 1987). Stach *et al.* (1982) identified three general topogenous swamp types based on plant associations: open water areas hosting aquatic plants; open marshes consisting of reeds with other herbaceous plants; and forest swamps (Figure 2.2). Ombrogenous conditions, although not necessarily resulting in a discrete moor ecology, lead to a nutrient-poor environment, promotes tissue breakdown and commonly a low mineral content peat (Moore 1989; Diessel, 1992; Taylor *et al.*, 1998; Figure 2.2). From studies of modern analogues, Wust and Bustin (2001) suggested these would yield vitrinite-rich coals.

Microbiological activity also varies with groundwater conditions and may exert a critical influence over coal type (Moore and Shearer, 2003). With unlimited access to oxygen, vegetable matter will be largely degraded, although a residue of resistant, liptinite-rich constituents may form (Taylor *et al.*, 1998; Table 2.1) and, in the case of ombrogenous coals, a finely detrital groundmass may result (Crosdale, 1993). Where direct access to oxygen is restricted by high atmospheric moisture, mouldering can occur from the action of aerobic bacteria and fungi, leading to inertinite-rich coals (Taylor *et al.*, 1998). Peatification occurs where plant debris becomes rapidly waterlogged and oxygen is further restricted, producing vitrinite-rich and inertinite-poor coals. In highly anaerobic, open water environments putrefaction occurs, producing well-gelified sapropelic coals, or a vitrinite-rich, finely detrital gyttjae (Taylor *et al.*, 1998). Overall, high groundwater levels promote preservation, while under low or fluctuating groundwater regimes the peat may become exposed, whereupon the degree of degradation increases (Moore and Shearer, 2003).




Mine and peat types modified after Stach *et al.* (1982), Flores (1993) and Taylor *et al.* (1998)

Figure 2.2 Peat variation with groundwater level

### *Swamp Conditions*

Swamp conditions such as pH, salinity, nutrient supply and temperature modify coal characteristics through the level of bacterial activity (influencing decomposition and gelification) and swamp flora (influencing source material: Cohen *et al.*, 1987; Teichmuller, 1989; Moore, 1991; Dehmer, 1995). Many types of bacteria thrive in neutral to weakly alkaline conditions, decreasing in abundance with increasing acidity. Highly acidic peats therefore tend to show enriched tissue preservation and a dominance of telovitrinite over detrovitrinite, while elevated pH settings, such as marine-influenced and calcium-rich environments show a high level of tissue destruction and gelification (Teichmuller, 1989). Freshwater influxes into swamps can also lead to elevated pH and Eh, which enhance microbial activity and tissue degradation (Moore, 1991).

Nutrient supply influences plant growth and vegetation type (Moore, 1989, 1995). Under uniform hydrological conditions, topogenic swamps receiving groundwater rich in dissolved nutrients can support a luxuriant growth and a broad range of species, producing vitrinite-rich coals with abundant telovitrinite. Conversely, in precipitation-fed ombrotrophic settings

where nutrients are limited, there is reduced species diversity and stunted growth, leading to poor tissue preservation and a relative increase in liptinite and inertinite components.

### *Other Local Factors*

The mechanism of peat accumulation influences coal type. Coals rich in telovitrinite and with little or no mineral are more likely to form under autochthonous conditions, while transportation of plant matter increases tissue degradation, elevates mineral content and leads to micro-layering. Allochthonous processes can also result in concentration of the more resistant macerals (e.g. corpogelinites, liptinites and inertinites; Taylor *et al.*, 1998).

Fires, particularly those involving surface vegetation within and surrounding the peat bog, can lead to the incorporation of inertinite within a predominantly unoxidised matrix (Cohen *et al.*, 1987; Rollins *et al.*, 1993). Under dry conditions, desiccation and peat combustion may occur producing inertinite-rich horizons and lead to major modifications to the local environment, such as topographic lows at the peat fire site, enhanced influx of mineral matter and a changed swamp chemistry (Teichmuller, 1989; Rollins *et al.*, 1993; Glasspool, 2003).

## 2.1.5.2 Tectonic and depositional setting

Tectonic factors affect the rate of basin subsidence, sediment influx and coal composition (Smyth, 1989) and, in turn, the number, thickness, continuity and quality of coal seams. Low sediment influx to a slowly subsiding depocentre, such as an intracratonic basin, is likely to lead to intermittent oxidation, resulting in elevated inertinite concentrations where accumulation of detrital organic matter exceeds subsidence (Ward, 1984). Where more rapid subsidence occurs, such as in orogenic areas, oxidation is less likely favouring formation of vitrinite-rich coals with increased petrographic diversity.

Coals occur in virtually all types of terrestrial depositional environments. Several correlation schemes have been developed that link clastic lithofacies and their accompanying coal facies (Hacquebard and Donaldson, 1969; Hunt and Hobday, 1984; Smyth, 1984, 1989; Kalkreuth and Leckie, 1989; Kalkreuth *et al.*, 1991; Diessel, 1992; Table 2.3; see also Section 2.1.7). Although the applicability of such relationships has been questioned (Moore and Shearer, 2003) some broad genetic associations have been proposed. For example, increasing inertinite and decreasing gelification appear to coincide with the transition from paralic to more inland settings. In addition, tissue preservation is generally greatest in fluvial settings and least in paralic settings, while marine-influenced coals are typically mineral rich (Teichmuller, 1989).

Table 2.3 Correlations reported between clastic lithofacies and adjacent coal facies

| Depositional Environment | Coal Attributes |
|---|---|
| Coastal strandplain/lower delta | Variable composition from high vitrinite/low inertinite to low vitrinite/high inertinite. Low tissue preservation. Vertical lithotype sequences. Elevated sulphur and mineral. |
| Fluvial/upper delta plain | Generally high vitrinite, low inertinite. Locally telovitrinite rich with increased inertinite in raised portions of the mire. Lightening upward lithotype sequences and rapid lateral changes in lithotype. Commonly low mineral. |
| Braid plain | Characteristically inertinite rich. Variable tissue preservation from low to moderate. High mineral and low sulphur content. |
| Lacustrine | Variable composition from high vitrinite/moderate inertinite to low vitrinite/high inertinite. Moderate liptinite, high mineral and low sulphur. Rapid lateral facies change. |

### 2.1.5.3 Climate and vegetation

Groundwater, vegetation, rate of peat production and bacterial activity are all related in one way or another to the prevailing climate, although its precise effect on coal characteristics is difficult to quantify because of the multiple parameters involved. Temperature and precipitation, in particular, regulate the nature and growth rate of the peat-forming vegetation and also have an important influence on peat decomposition. Plant growth is most prolific in warmer and wetter settings, although this climatic regime also promotes bacterial and fungal decomposition (Stach *et al.*, 1982; Teichmuller, 1989). In general, coals from warmer settings tend to be richer in detrovitrinite relative to those from cooler settings; and for constant temperature conditions inertinite increases as precipitation decreases. Climatic factors also influence the form and abundance of some plant constituents (notably cutinite and resinite) and lead to seasonal variations in the water table, which in turn modify petrographic properties (Dehmer, 1995; Holdgate *et al.*, 1995).

Peat constituents reflect the evolutionary stage of terrigenous vegetation at the time of deposition. The advent of an increased angiosperm contribution to forest ecosystems during the Late Cretaceous typically resulted in fewer and smaller spores (sporinite) and a considerably increased abundance of cork tissue (suberinite) in coals of this age and younger. In addition, angiosperm-rich floras are more diverse and specialised with respect to climatic and swamp settings than the gymnosperms, leading to increased stratification and coal type diversity in response to small changes in local depositional conditions. Kershaw *et al.* (1991) attributed increased up-sequence coal differentiation to the development of flora better adapted to a range of local environments. Wood type is also important. As highlighted by Crosdale (1993) and Shearer *et al.* (1995), the vascular tissue in gymnosperms has a greater resistance to fungal and bacterial decay than does that in angiosperms, leading to enhanced preservation of the former over the latter.

### 2.1.6 Petrographic trends and cyclicity

Stratigraphic variations in petrographic character through a seam or sequence have been noted from coalfields of different ages and tectonic settings (Smyth and Cook, 1976; Stach *et al.*, 1982; Styan and Bustin, 1983; Mackay *et al.*, 1985; Raymond *et al.*, 1987; Teichmuller, 1989; Anderson and Mackay, 1990; Kalkreuth *et al.*, 1991; Marchioni and Kalkreuth, 1991; Diessel, 1992; Crosdale, 1995; Kolcon and Sachsenhofer, 1999; Wust and Bustin, 2001; Crosdale *et al.*, 2002; Glasspool, 2003; Amijaya and Littke, 2005; Silvia and Kalkreuth, 2005). Upward-lightening sequences (i.e. the trend from dark, to light and ultimately pale varieties) in brown coals and upward gradations from bright to dull in hard coals are the most commonly reported, while increased banding and differentiation toward the roof of a seam is sometimes noted (Mackay *et al.*, 1985; Crosdale, 1995; Holdgate *et al.*, 2000; Figure 2.3). Trends and cycles within seams are caused by depositional sequence-scale events, whereby peat accumulation responds to inherent factors such as changes in groundwater level or flora (Johnson, 1995). The broad geographic and temporal range of coals showing such evolutionary trends suggests this is a relatively common and normal phenomenon in peat accumulation.

Cycles of lightening-upward lithotypes in brown coals have been interpreted to record the transition from topogenous to ombrogenous conditions and an increasingly aerobic environment, with the sharp reversion from pale to dark lithotypes reflecting a new cycle and rapid increase in groundwater level (Mackay *et al.*, 1985; Anderson and Mackay, 1990; Crosdale, 1995; Holdgate *et al.*, 1995). In higher rank coals, upwardly decreasing vitrinite content and increasing inertinite are thought to signify increasingly aerobic conditions as peat growth outstrips subsidence. This is paralleled by an evolution from open water to wet eutrophic forest swamp and, ultimately, to dryer oligotrophic conditions (Smyth and Cook, 1976; McCabe, 1987; Cameron *et al.*, 1989; Teichmuller 1989). Within a sequence stratigraphy framework these changes signify transgressive and regressive seams, respectively (Diessel, 1992; Holz *et al.*, 2002). Conversely, cannel coals and well gelified brown coal at the tops of seams have been recognised as reflecting progressively wetter conditions due to increased subsidence or eustatic variations (Easterle and Ferm, 1986; Diessel, 1992; Teichmuller, 1989; Holdgate *et al.*, 2000; Crosdale *et al.*, 2002; Bechtel *et al.*, 2004).

In addition to regular cyclic changes in coal characteristics, fire is an important modifier of the peat-forming environment (Teichmuller, 1989; Rollins *et al.*, 1993). Abrupt facies and palaeoenvironmental changes may result, such as replacement of dense forest swamp environments by open water lake, or reed swamps.

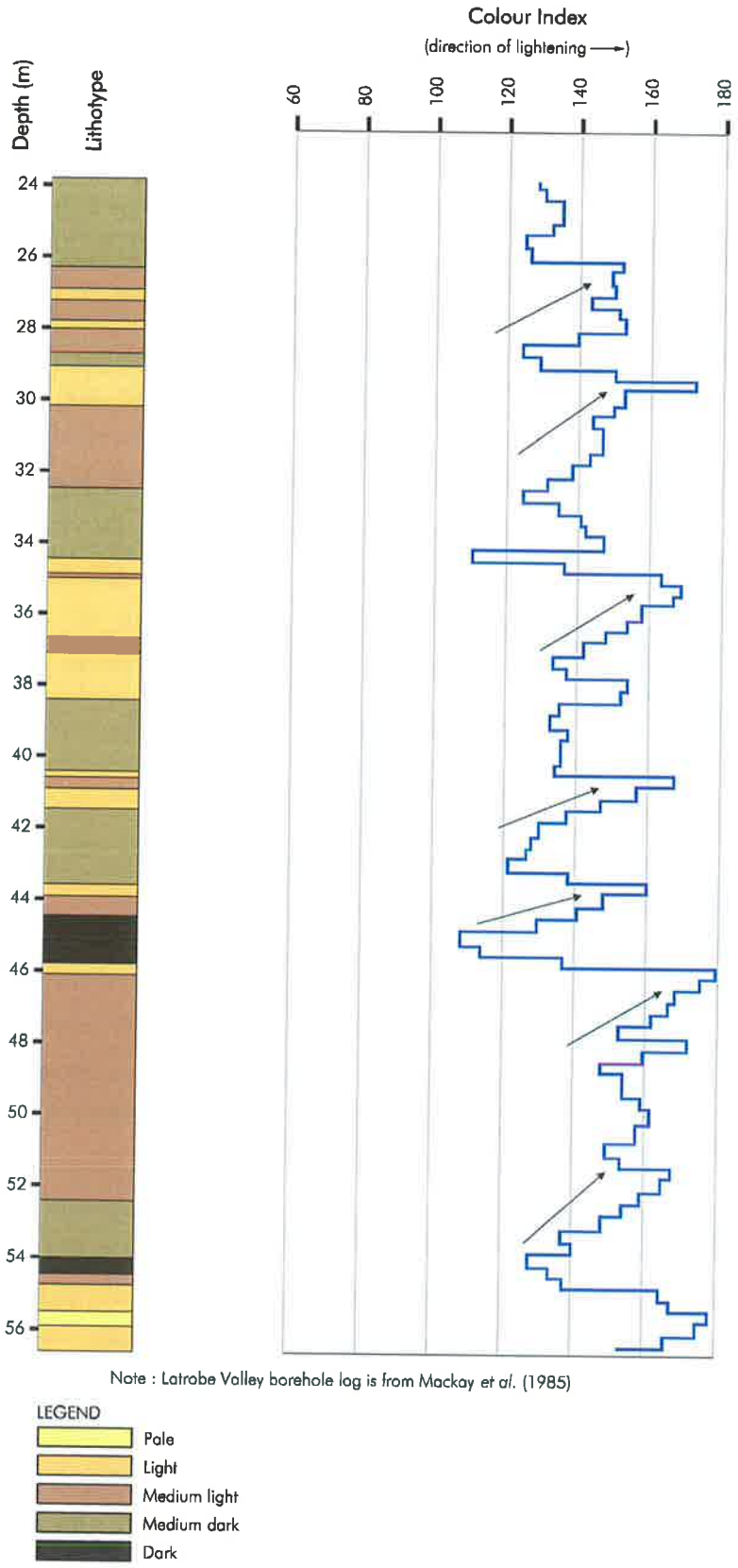



Figure 2.3 Upward-lightening lithotype sequences in Latrobe Valley brown coals

### 2.1.7 Coal characteristics and palaeoenvironments

#### 2.1.7.1 Coal composition and facies

Teichmuller (1989) summarised the generally accepted environmental inferences based on gross maceral content, whereby coals rich in vitrinite are indicative of relatively wet conditions of peat formation. Conversely, coals rich in inertinite, especially fusinite, semifusinite and macrinite, are more likely to be generated from peats deposited under relatively dry conditions. In addition, several studies (mainly of pre-Tertiary topogenic coals) have assessed the manner and extent to which coal type can be related to more specific palaeoenvironments, focussing on both the local swamp environment (Hacquebard and Donaldson, 1969; Diessel, 1982, 1986, 1992; Styan and Bustin, 1983; Kalkreuth and Leckie 1989; Kalkreuth *et al.*, 1991; Mavridou *et al.*, 2003) and the regional depositional setting (Hacquebard and Donaldson, 1969; Smyth, 1984, 1989; Kalkreuth and Leckie, 1989; Kalkreuth *et al.*, 1991; Michaelson and Henderson, 2000). Such evaluations are based on specific parts or types of plants, and parameters that are indicative of particular biogeochemical conditions.

Some of the earliest correlations between coal characteristics and peat-forming palaeoenvironment were those established by Hacquebard and Donaldson (1969) using microlithotypes. Diessel (1982) pioneered the development of maceral ratios, whereby individual macerals were categorised in relation to their likely source and level of modification. Using this approach, Diessel (1982, 1986, 1992) defined a Tissue Preservation Index (TPI) and a Gelification Index (GI), quantifying the relative abundance of structured and degraded macerals (a measure of humification) and the proportion of vitrinite to inertinite components (to assess the continuity of moisture availability). These indices enabled the recognition of assorted local palaeoenvironments, ranging from forest swamp to sub-aqueous. Similar concepts have been applied by other workers (Kalkreuth and Leckie, 1989; Kalkreuth *et al.*, 1991; Marchioni and Kalkreuth, 1991; Silva and Kalkreuth, 2005) and, in some cases, modified for specific application to low-rank Tertiary coals (George, 1982; Kolcon and Sachsenhofer, 1999; Table 2.4).

Table 2.4 Maceral indices applied for palaeoenvironmental evaluation

| Index | Maceral Derivation | Conditions / Properties Assessed |
|---|---|---|
| Tissue preservation | (i) [(telovitrinite + telo-inertinite)] / [(detrovitrinite +gelovitrinite + detro-inertinite + gelo-inertinite)]<br>(ii) [(telovitrinite + semifusinite + fusinite)] / [(detrovitrinite+ macrinite + sclerotinite)] | Preservation and humification |
| Gelification | (i) [(vitrinite + gelo-inertinite)] / [(telo-inertinite + detro-inertinite)]<br>(ii) [(total vitrinite + macrinite)] / [(semifusinite + fusinite + sclerotinite)]<br>(iii) [(densinite + eu-ulminite + porigelinite +1/2 x corpogelinite)] | Moisture availability |
| Groundwater influence | (i) [(gelovitrinite + mineral)] / [(telovitrinite + detrovitrinite)]<br>(ii) [(detrovitrinite + mineral)] / [(telovitrinite)] | Mire type, gelification |
| Vegetation | [(telovitrinite + telo-inertinite + suberinite + resinite)] / [(detrovitrinite + inertodetrinite + liptodetrinite +alginite + sporinite + cutinite)] | Mire type (forest, open water) |
| Structured to groundmass vitrinite | [(telovitrinite) / (detrovitrinite + gelovitrinite)] | Tissue preservation, source matter |
| Structured to groundmass inertinite | [(semifusinite + fusinite)] / [(inertodetrinite + macrinite + micrinite)] | Tissue preservation |
| Vitrinite to inertinite | [(total vitrinite)] / [(total inertinite)] | Mine setting and type |
| Vitrinite to telo-inertinite | [(total vitrinite)] / [(fusinite + semifusinite)] | Moisture availability |
| Forest to sub-aquatic | (i) [(telovitrinite + fusinite + semifusinite)] / [(alginite + sporinite + inertodetrinite)]<br>(ii) [(telovitrinite + fusinite + semifusinite)] / [(alginite + sporinite + inertodetrinite + detrovitrinite + gelovitrinite)] | Mire type (reed, forest), preservation |

Correlations between coal composition and depositional environment reveal some broad trends that can be primarily related to regional groundwater conditions and subsidence. High vitrinite content and high tissue preservation have been noted in fluvial coals (Hacquebard and Donaldson, 1969; Diessel, 1992), while lacustrine coals are typically inertinite and vitrinite poor, with a low to variable tissue preservation and low gelification (Hacquebard and Donaldson, 1969; Smyth, 1984, 1989). Similar characteristics were reported by Diessel (1992) in coals from braid plain and topographic basin settings. In coastal settings, vitrinite-rich, inertinite-poor and highly gelified coals with low tissue preservation have been noted (Smyth, 1984, 1989; Diessel, 1992).

Although assorted relationships have been identified, the applicability of maceral indices to the task of palaeoenvironmental interpretation has been questioned, particularly in the case of Tertiary ombrogenous coals (Crosdale, 1993, 2004; Dehmer, 1995; Wust *et al.,* 2001; Scott, 2002; Moore and Shearer, 2003; Amijaya and Littke, 2005). For example, neither vegetation type, relative degree of aeration or maceral composition was considered to be solely dependent on depositional environment. Furthermore, the usefulness of correlations between coal characteristics and regional sedimentary setting has been queried (McCabe, 1987; Michaelson and Henderson, 2000; Moore and Shearer, 2003; Crosdale, 2004), while Smyth

(1989) noted variations in coal characteristics for similar palaeoenvironments. In this regard, peat development in environments distinctly different from that of the underlying sediment; peat accumulation during periods of clastic sediment starvation; and the importance of groundwater levels for tissue preservation, have been highlighted as limiting factors.

In summary, these studies show that compositional parameters are dependent on the interplay of numerous factors and cannot be universally applied. However, within a specific deposit or region they may prove useful for palaeoenvironmental reconstruction.

### 2.1.7.2 Seam splitting and geometry

Seam characteristics such as thickness, lateral extent and nature of termination have been related to regional depositional setting (Hacquebard and Donaldson, 1969; Ferm and Staub, 1984; McCabe, 1987; Kalkreuth *et al.*, 1991), although some degree of variability is evident within any particular environment (Figure 2.4). Correlations have also been established between petrographic properties and proximity to seam splitting and overbank sedimentation (Kravitis and Crelling, 1981; Ferm and Staub, 1984; Esterle and Ferm, 1986; Kalkreuth *et al.*, 1991) and sequence stratigraphy setting (Holz *et al.*, 2002).

In coastal back-barrier settings, contrasting characteristics ranging from thin, lenticular and laterally discontinuous seams with numerous splits (Galloway and Hobday, 1983; Styan and Bustin, 1984; Johnson, 1995), to seams of great lateral continuity and substantial thickness (Kalkreuth *et al.*, 1991; Diessel, 1992) have been reported. Diessel (1992) related this variability to differences in rates of basin subsidence and shoreline progradation. However, a relatively consistent feature of back-barrier deposits is their distinct orientation parallel to the shoreline. The lower delta plain tends to generate thin coals with frequent splitting and landward gradation into thicker seams in the upper delta plain (Hacquebard and Donaldson, 1969; Diessel, 1992). Similar attributes have also been reported for estuarine coals. Seam characteristics variously noted in upper delta plain coals include thick, isolated and laterally restricted (Hacquebard and Donaldson, 1969; Styan and Bustin, 1984); moderate thickness and extensive development (Fielding, 1985); and thin and discontinuous (Kalkreuth *et al.*, 1991). In this setting, thickness variations were found to primarily relate to abrupt seam splitting (Ferm and Staub, 1984), commonly in response to rapid subsidence.

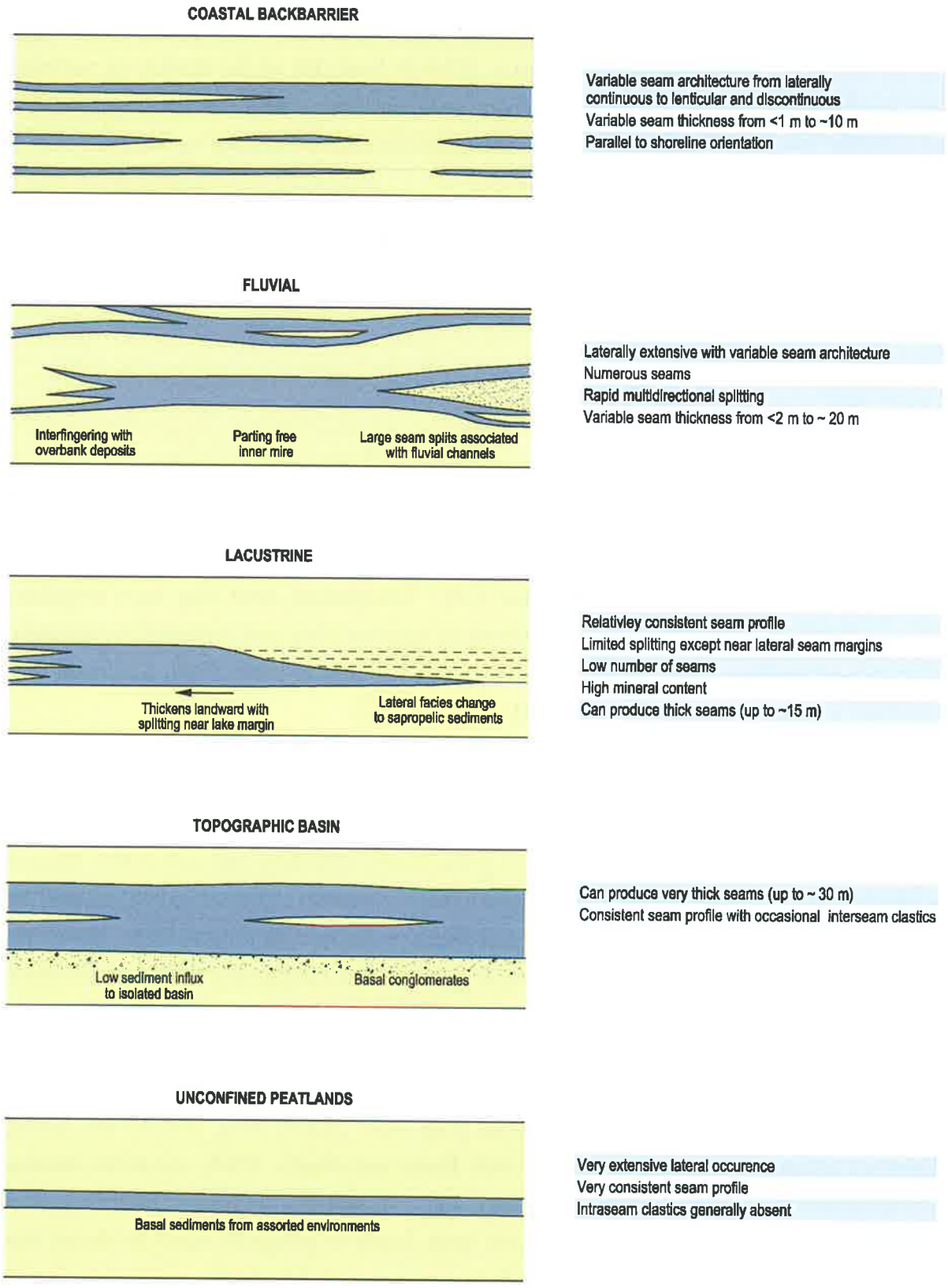



Figure 2.4 Generalised seam characteristics with depositional setting

Flood plain coals are commonly laterally extensive and contain numerous seams, displaying a thicker central inter-channel section, with rapid multidirectional splitting as fluvial channels and crevasse splay deposits encroach (Galloway and Hobday, 1983; Fielding, 1985; Johnson, 1995: Moore *et al.*, 2000). Seam thickness typically ranges from 2 to 10 m, but may reach up

to 20 m, and typically the seam is elongated parallel to the channel orientation. New channels developed by avulsion tend to correspond with areas of maximum peat accumulation in the underling seam (coincident with greatest compaction) and can result in a pattern of laterally offset depocentres (Hacquebard and Donaldson, 1969; Holdgate, 1985; Hager, 1993). Coals from the braid plain setting are thin to moderate, can be laterally extensive and show rapid splitting and thinning (Johnson, 1995).

Settings with more consistent attributes include topographic basins, lacustrine environments and unconfined peatlands. In the former settings, very thick coals can form with splitting away from the depositional centre, or termination by laterally increasing detrital sediment (Hacquebard and Donaldson, 1969), while in the latter extensive coals with consistent seam profiles and limited splitting may result (Johnson, 1995).

The sequence stratigraphy of paralic coals was reviewed by Holz *et al.* (2002) who noted that lowstand systems tract coals are continuous and moderately thick, while those in transgressive systems tracts vary from thick and relatively isolated to thin and discontinuous. Thicker accumulations tend to occur early and later in the transgressive systems tract, with thinner varieties in the middle.

## 2.2 DEPOSITIONAL MODELS FOR BROWN COAL LITHOTYPES

Various models have been postulated to explain the origin of brown coal lithotypes and in particular the light and dark bands, with debate largely revolving around the relative importance of source material/swamp setting, versus the biomechanical conditions under which it accumulates. In brown coals, plant remains including wood, pollen and cuticle can often be accurately identified and palaeobotany has been extensively used with coal petrology in the evaluation of depositional environments. Pioneering work was largely based on the Miocene brown coals of the Lower Rhine Embayment, Germany, and more recently has involved the Eocene to Miocene coals of the Gippsland Basin, Australia. The nature of these studies and the methods they employed are documented by Dehmer (2004) and Crosdale (2004), respectively.

### 2.2.1 Swamp setting

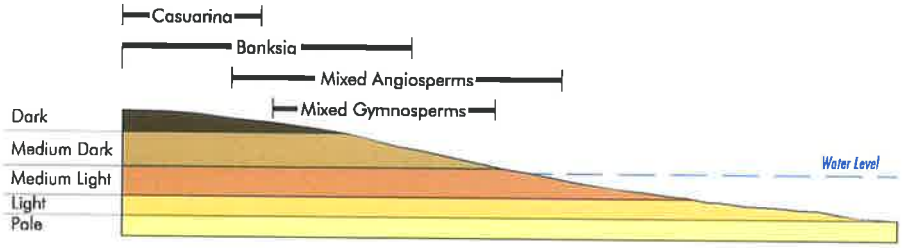
Some of the earliest lithotype reconstructions, developed during the 1950s, employed palaeobotany to recognise assorted depositional settings for peats and associated organic-rich sediments, including open water, reed swamp, wet forest swamp, drier bush swamp and still drier coniferous forest (Teichmuller, 1989; Taylor *et al.*, 1998; Figure 2.5a-i). Areas of open

## a. Swamp Setting Model

(i) Palaeobotanical reconstruction using Miocene Rhenish brown coal (after Teichmuller, 1989)

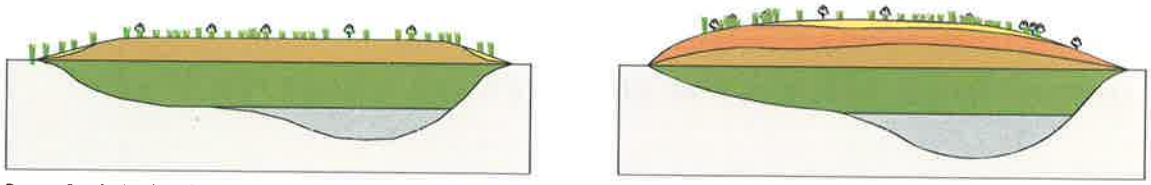
| MOOR TYPE | FOREST - Varying in line with hydrological conditions | REED MARSH | OPEN WATER |
|---|---|---|---|
| | Sequoia / Myricaceae - Cyrillaceae / Nyssa Taxodium | | |
| RESULTING COAL | Dark brown with coalified tree stems (xylitic). Telovitrinite rich | Light brown, Tissue poor. | Dark, tough brown liptinite rich, tissue poor. Clay minerals common |

(ii) Palaeobotanical reconstruction using Eocene and Miocene brown coals from the Latrobe Valley (after Balme *et al.*, 1995)




## b. Microbiological Model

Lithotype sequences and coal petrology using Eocene and Miocene brown coals from the Latrobe Valley (after Anderson and McKay, 1990)



Dome : Poorly developed
Lithotypes : Medium - light, medium - dark and dark. Light lithotypes may develop in areas of low subsidence near dome margins

Dome : Highly Developed
Lithotypes : Vertically zoned peat with light and pale lithotypes forming in central area and overlying darker lithotypes. Darker lithotypes may also form near dome margins.

LEGEND

Light and pale | Medium light and medium dark | Dark, medium - dark and medium light | Clayey peat | Organic rich clay

## c. Integrated Model

Source and microbial factors and eustatic and climatic variations (after Holdgate *et al.*, 1995)

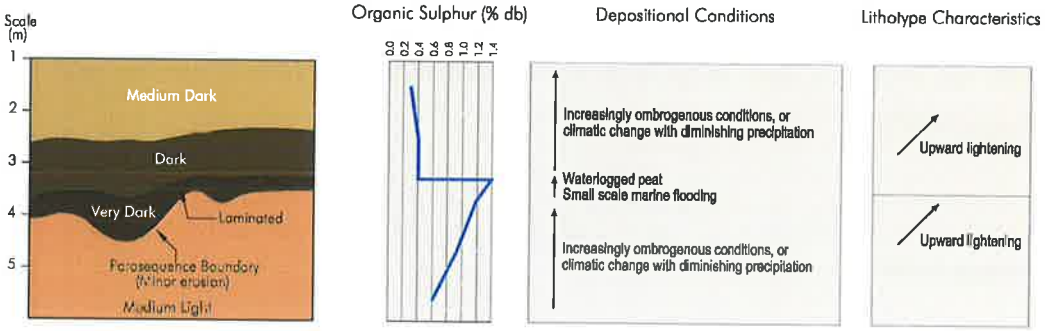



Figure 2.5 Brown coal lithotype models

water were postulated to be the site of organic-rich muds (gyttjae) and mineral rich peats. These form from the remnants of floating plants (including algae) and allochthonous material, producing either liptinite-rich (alginite, sporinite) and vitrinite-poor pale coals, or vitrinite-dominated dark varieties. A peat rich in humic detritus and poor in structured vitrinites was interpreted for the lignin-poor herbaceous plants (with some allochthonous matter) in the reed swamp, while woody telovitrinite-rich lithotypes (mainly autochthonous) were envisaged for the forest swamps. The former setting favoured the formation of lighter coloured bands, reflecting the above average liptinite content, while the latter with less liptinite input (principally resinite, suberinite and cutinite) produced dark lithotypes.

Later palaeobotanical lithotype to swamp setting correlations (Kershaw and Sluiter, 1982; Kershaw *et al.*, 1991; Figure 2.5a-ii) broadly supported the model of Teichmuller (1989), recognising open water (light and pale coals), mostly autochthonous swamp forest (medium light and medium dark coals) and emergent forest swamp (dark coals). Using organic geochemistry, Chaffee and Johns (1985) likewise deduced that the lithotypes were derived from differing palaeobotanical communities. However, Kershaw *et al.* (1991) also noted a gradual further differentiation of lithotypes over geological time and identified other factors possibly influencing lithotype, such as increasing floral heterogeneity, climatic changes and more frequent occurrence of fires.

### 2.2.2 Microbiological modification

As an alternative to the aforementioned palaeobotanical-based reconstructions, Mackay *et al.* (1985) and Anderson and Mackay (1990) proposed the use of lithotype sequences in combination with coal petrology (Figure 2.5b). Highlighting the significance of biogeochemical modification, these authors noted that on a coarse scale (i.e. over several metres), lithotypes tend to lighten upward, with sharp reversals to dark coal completing the cycle, and suggested that lithotype cycles commence with waterlogged peats. Progressively lighter lithotypes up sequence were interpreted to reflect increasingly ombrogenous conditions and more prolonged aerobic degradation. Pale and light coals were considered to be the most severely degraded, reflecting conditions of intense aerobic degradation where peat accumulation outstripped subsidence.

Anderson and Mackay (1990) suggested that the slowest deposition occurred in the central portions of prominent ombrogenous domes, where nutrient depletion and aerobic conditions in the peat precursors, lead to the formation of light and pale lithotypes. In areas of relatively rapid subsidence (i.e. limited dome development), accumulation of dark, medium dark and medium light lithotypes were inferred. These authors concluded that palaeobotanical/lithotype correlations were not spurious, but rather a secondary characteristic reflecting floral zonation

in line with nutrient supply. Furthermore lightening-upward cycles and reduced tissue preservation were considered a natural consequence of peat dome development (Anderson and Mackay, 1990; Crosdale, 1995).

Assorted organic geochemical investigations (Hagemann and Hollerbach, 1980; Winkler, 1986; Hagemann and Wolf, 1987) have also highlighted the importance of biogeochemical transformation in determining lithotype, with the level of microbial degradation thought to vary with factors such as acidity, oxygen availability, water inundation and nutrient supply. Hagemann and Hollerbach (1980) detected biomarker variations with lithotype and postulated different kinds and intensities of biogeochemical processes were responsible, while Winkler (1986) and Hagemann and Wolf (1987) concluded the differing lithotypes did not appear to relate to changing plant communities. Hagemann and Hollerbach (1980) and Hagemann and Wolf (1987) suggested darker coals had been subjected to more intense anaerobic decomposition than other varieties and accumulated in an anoxic setting below the groundwater table, while the light to pale coals were generally underwent strong aerobic decay.

### 2.2.3 Integrated model

Recently advanced scenarios of lithotype formation incorporate both source-related factors and microbial modification and highlight the significance of eustatic and climatic variation (Holdgate *et al.*, 1995; Sluiter *et al.*, 1995; Holdgate *et al.*, 2000; Figure 2.5c). Elevated organic sulphur levels at the top of the lightening-upward cycles (i.e. at the dark over light lithotype boundary), minor erosional features at cycle boundaries, a regionally mappable occurrence of the dark lithotypes, and episodic peat formation lead Holdgate *et al.* (1995) to correlate peat accumulation in the Gippsland Basin with peak marine levels and subtropical climatic conditions.

The darker layers at the base of the cycle were considered the most waterlogged, following small-scale marine flooding, while the lightening up trend was taken to reflect either; doming of the peat surface and increasingly ombrogenous and aerobic conditions, or climate change and reduced rainfall. Nutrient starvation and higher acidity associated with increasing doming were thought responsible for termination of peat development. The lightening-upward lithotype cycles and their unique boundary conditions (i.e. erosional upper surface and increased organic sulphur) were interpreted as parasequences and parasequence boundaries, respectively (Holdgate *et al.*, 1995; Crosdale, 2004). In conjunction with the research of Holdgate *et al.* (1995), palynological based reconstructions were reassessed by Sluiter *et al.* (1995) and all peat formation postulated under a continuous cover of vegetation, devoid of open water phases. Furthermore, the dense swamp forest was thought to lead to the

preservation of the darkest lithotypes and the ombrogenous settings the lightest. Climatic controls and related eustatic changes were suggested as the major influence over lithotype formation.

Notwithstanding the extensive previous research on the environmental significance of individual lithotypes, Crosdale (2004) noted that many uncertainties remain regarding their development and highlighted the importance of local climate and groundwater hydrology as modifiers of peat forming environments. Furthermore, Dehmer (2004) suggested additional investigation was required into detrovitrinite formation and liptinite enrichment to refine palaeoenvironmental interpretation.

## 2.3 BROWN COAL EVALUATION AND ATTRIBUTES

### 2.3.1 Differentiation

Systems for differentiating brown coals involve either macropetrographic (i.e. lithotype) or micropetrographic (i.e. maceral) criteria, or a combination of the two (Table 2.5). However, the extent to which these systems are genetically based varies considerably. Teichmuller (1989) indicated that features such as maceral composition, mineral inclusions and texture may be used to define genetic lithotypes, suggesting macroscopic and microscopic criteria can be related.

Table 2.5 Brown coal differentiation systems

| Criteria | Key Parameters | Secondary Parameters | Basis |
|---|---|---|---|
| Lithotype | Texture and wood content | Colour | Genetic |
| Lithotype | Texture, wood content, inertinite and mineral abundance | Stratification, colour, gelification | Genetic/technical |
| Lithotype | Texture and mineral abundance | Colour, gelification, organic inclusions, nature of fracturing | Genetic/descriptive/ technical |
| Lithotype | Colour | Texture, wood content, gelification, mineral abundance, hardness | Descriptive |
| Maceral | Maceral associations | | Genetic |
| Maceral | Tissue decomposition and maceral associations | | Genetic |
| Lithotype and maceral | Texture, maceral and mineral abundance | | Genetic |

#### 2.3.1.1 Lithotypes

Lithotypes are macroscopic units of coal, distinguished primarily by qualitative evaluation of their physical properties. Brown coal lithotype classifications are commonly developed for a specific deposit, or sedimentary region. Hence a broad range of lithotype schemes exist,

ranging from those that are purely descriptive to those with a genetic basis (Francis, 1961; Nichols and Traverse, 1971; George, 1975, 1982; Hagemann and Hollerbach, 1980; Mukhopadhyay, 1986; Hagemann and Wolf, 1987; McCabe, 1987; Diessel, 1992; ICCP, 1993; Taylor *et al.*, 1998; Amijaya and Littke, 2005; Ercegovac *et al.*, 2006). Diessel (1992) noted that while some systems are not necessarily genetically based, they may reflect changes in palaeoenvironment over the limited area where the coals in question occur, while McCabe (1987) suggested that basin-specific schemes might be more useful than a universal classification. While several other macroscopic features can be used, texture and colour commonly are the key parameters. Lithotype systems differ primarily in the preference given to these two characteristics.

Francis (1961) developed one of the earliest brown coal lithotype classifications. Using appearance (i.e. primarily texture), coals were differentiated into three varieties: earthy brown or fibrous, woody, and amorphous. Hagemann and Hollerbach (1980) also used texture, defined as the ratio of tissue to the groundmass to plant remains, to define four lithotypes (viz. unbanded, moderately banded, banded and highly banded), with other characteristics including colour, gelification and the proportion of plant debris used to assist differentiation. Mukhopadhyay (1986) used a version of this system that was expanded to include pure and impure unbanded lithotypes. A variation on the texture-based scheme was developed by the ICCP (1993), in which both genetically and technically important components were highlighted. This used xylite, groundmass and compositional features such as charcoal and mineral content to define four lithotype groups: matrix, xylite, charcoal rich and mineral rich. Matrix coal, consisting predominantly of fine detrital groundmass, was further classified using the degree of stratification.

A lithotype classification system based primarily on air-dried colour was developed by George (1975, 1982) for the brown coal deposits of Victoria in which five varieties were defined (viz. dark, medium-dark, medium-light, light and pale), allowing differentiation at a specific site and rank. Other secondary parameters used in a descriptive manner included texture, proportion of tissue to groundmass, gelification, various physical properties and weathering. Several studies concluded the colour of brown coals can be independent of facies and therefore represents a secondary characteristic (Hagemann and Hollerbach, 1980; Mackay *et al.*, 1985; Hagemann and Wolf, 1987; George and Mackay, 1991). In particular, Hagemann and Hollerbach (1980) found colour intensity and tissue content to be largely independent, while Mackay *et al.* (1985) noted a range in petrographic characteristics within a single lithotype, including distinctly different coals within the dark grouping and differences between the colour of groundmass and tissue. Furthermore, Winkler (1986) and George and Mackay (1991) concluded that specific colour-defined lithotypes could not be related to a single depositional environment.

### 2.3.1.2 Maceral composition

A comprehensive genetic classification applicable to coals of all rank was developed by the Academy of Sciences of the USSR (ICCP, 1971), using maceral composition and the degree of tissue preservation as key defining parameters. Maceral components were grouped according to depositional associations (i.e. gelification, gelo-fusinisation or fusinisation), corresponding to varying water regimes during peat accumulation, while tissue degradation was classified from slight to almost complete, reflecting increasing biochemical and mechanical breakdown. A total of 27 individual coal types were identified and various key environmental factors postulated, such as the degree of flooding, swamp-water chemistry and mobility, depositional setting and rate of subsidence.

Quantitative maceral evaluation is commonly used to highlight compositional similarities, identify facies and infer palaeoenvironment (Diessel, 1986, 1992; Kalkreuth and Leckie, 1989; Kalkreuth *et al.*, 1991; Marchioni and Kalkreuth, 1991). While not representing a formal classification, this approach generally allows for local genetic differentiation of lithotypes. Maceral parameters have been related to vegetation type and the degrees of oxidation, gelification and tissue preservation. Classification of sapropelic coals represents a further application of maceral data, whereby these macroscopically homogenous dark and frequently mineral-rich coals can be readily divided into two cannel varieties and a boghead type (Taylor *et al.*, 1998).

In brown coals maceral assemblages have been used to define coal varieties (Amijaya and Littke, 2005) and in combination with chemical and technological parameters, to develop a genetic-industrial classification (Ercegovac *et al.*, 2006).

### 2.3.2 Biomarker content

Biomarkers are molecular fossils derived from formerly living organisms that occur in sediments and can potentially be linked to specific biological precursor compounds. Several classes of biomarker have been detected in brown coals, including acyclic normal and isoprenoid alkanes and cyclic aliphatic hydrocarbons such as sesquiterpenoids, diterpenoids, triterpenoids, steroids and hopanoids (Hagemann and Hollerbach, 1980; Chaffee, 1981; Noble *et al.*, 1986; Simoneit *et al.*, 1986; Winkler, 1986; Wang and Simoneit, 1990; Stout, 1992; Ming *et al.*, 1994; Dehmer, 1995; Springbett and McKirdy, 1999; Bechtel *et al.*, 2002; Bechtel *et al.*, 2004; Figure 2.6; Table 2.6).

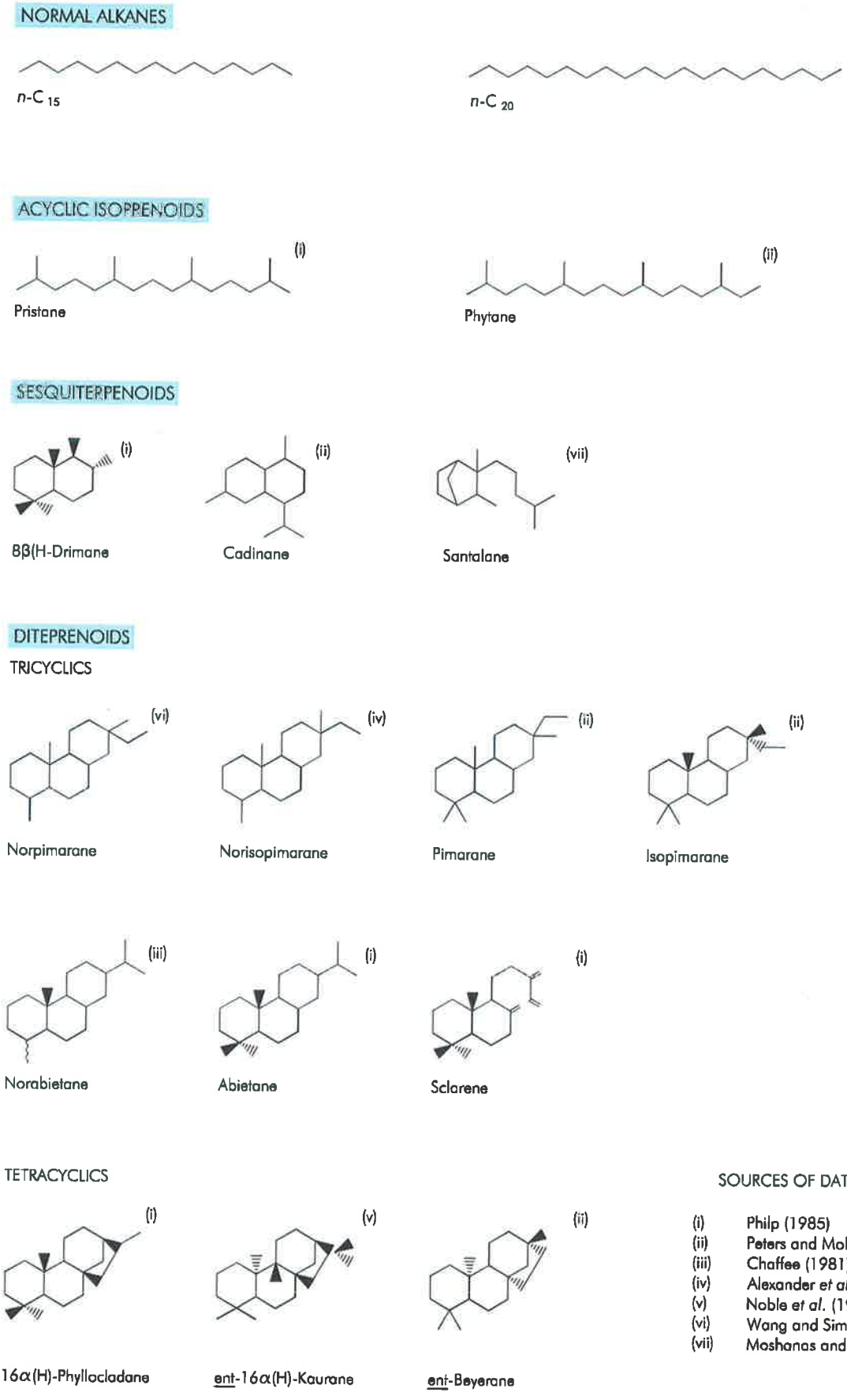
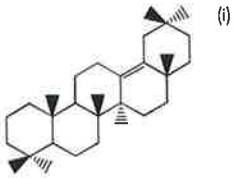



Figure 2.6a Carbon skeletons of selected brown coal biomarkers (sheet 1of 2)

REGULAR NON HOPANOID TRITERPENOIDS

Olean-12-ene

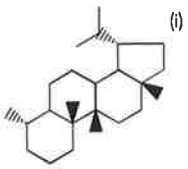



Olean-13(18)-ene

SOURCES OF DATA

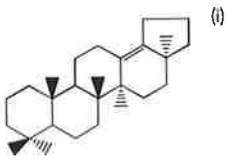
(i) Philp (1985)
(ii) Peters and Moldowan (1993)
(iii) Chaffee (1981)
(iv) Alexander *et al.* (1988)
(v) Noble *et al.* (1986)
(vi) Wang and Simoneit (1990)
(vii) Moshanas and Lund (1970)

DES-A TRITERPENOIDS

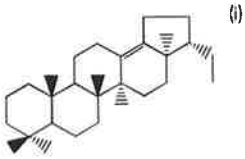



Des-A-lupane

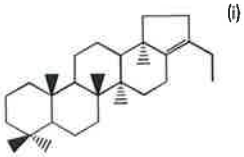
HOPANOIDS



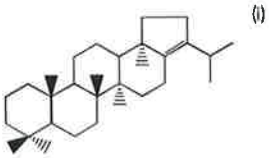

22,29,30-Trisnorhop-13(18)-ene



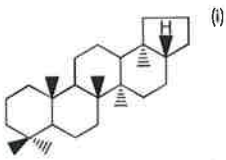

30-Normoohop-13(18)-ene



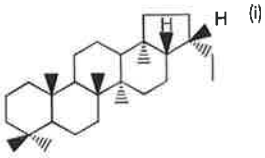

30-Norhop-17(21)-ene



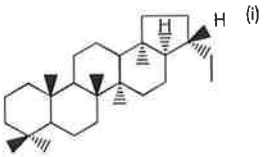

Hop-17(21)-ene



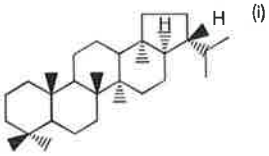

17$\beta$(H)-22,29,30-Trisnorhopane




17$\beta$(H),21$\beta$(H)-30-Norhopane

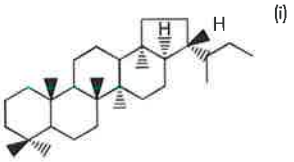



17$\alpha$(H),21$\beta$(H)-30-Norhopane

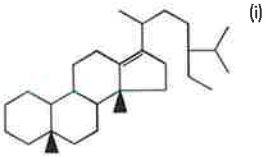



17$\alpha$(H),21$\beta$(H)-Hopane

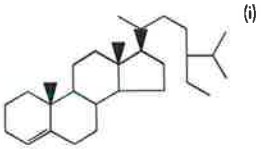
STEROIDS




17$\alpha$(H),21$\beta$(H)-Homohopane




24-Ethyl-Diacholest-13(17)-ene




24R-24-Ethylcholest-4-ene

Figure 2.6b Carbon skeletons of selected brown coal biomarkers (sheet 2 of 2)

Table 2.6 Biomarker groups and major compounds detected in brown coals

| Group | Occurrence | Compounds Reported / Biological Origin and Environment |
|---|---|---|
| Normal alkanes | Very common | Odd numbered members in *n*-$C_{21}$ to *n*-$C_{35}$ range. *n*-$C_{27}$, *n*-$C_{29}$, *n*-$C_{31}$ suggested as indicators for higher plant and terrigenous environments (Eglinton and Hamilton, 1967). |
| Acyclic isoprenoids | Rarely reported | $C_{15}$-$C_{20}$ regular isoprenoids, e.g. pristane and phytane. |
| Sesquiterpenoids | Uncommon | Cadinane and partially or fully aromatised counterparts, eudesmane. Suggested as gymnosperm markers, more specifically α-cedrene and cuparene as markers for *Cupressaceae* (Grantham and Douglas, 1980; Chaffee *et al.*, 1986; Otto *et al.*, 1997). |
| Diterpenoids | Common | Mixed tricyclic/tetracyclic assemblages most common. Tricyclics include abietane and pimarane skeletons. Tetracyclics include phyllocladane and kaurane skeletons. Tetracyclic diterpanes suggested as conifer markers and indicators of terrestrial environments and more specifically phyllocladane as a marker for *Podocarpaceae,* (Noble *et al.*, 1985, 1986; Otto *et al.*, 1997). |
| Regular non hopanoid triterpenoids | Common | Oleanenes, ursenes, minor lupanoids and fernenes. Suggested as angiosperm indicators, (Chaffee *et al.,* 1986; Wang and Simoneit, 1990; Killops *et al.,* 1995). Oleananes possibly sensitive to post- depositional marine influence (Murray *et al.*, 1997). |
| A-ring contracted triterpenoids | Very Rare | Oleanene and ursene skeleton derivatives. |
| Des-A triterpenoids | Uncommon | Lupane, oleanane and ursane skeletons derivatives. Suggested as angiosperm indicators (Weston *et al.*, 1989; Stout, 1992, Killops *et al.,* 1995). |
| Hopanoids | Very common | Hopenes and β/ββ compounds are common, αβ compounds are very widespread with βα are less common. Rare 17,21-secohopanes and 8,14-secohopanes. 22R-17α(H),21β(H)-homohopane suggested as a bacterial indicator (Chaffee *et al.,* 1986) and hop-17(21)-ene suggested as a marker for anaerobic bacteria (Bechtel *et al.*, 2004). |
| Steroids | Uncommon | Mainly diasterenes. Diasteranes suggested as indicators for higher plants (van Aarssen *et al.*, 1996). |

### 2.3.2.1 Acyclic alkanes

Normal alkanes are widely recognised brown coal biomarkers and typically constitute a significant portion of the aliphatic hydrocarbon fraction (Wang and Simoneit, 1990; Stout, 1992; Dehmer, 1995). Their distribution is typically dominated by odd-carbon-numbered homologues (i.e. odd over even predominance) within the range *n*-$C_{21}$ to *n*-$C_{35}$, and usually maximises at *n*- $C_{27}$, *n*- $C_{29}$ or *n*- $C_{31}$ (Hagemann and Hollerbach, 1980; Chaffee and Johns, 1985; Chaffee *et al.*, 1986; Winkler, 1986; Hazai *et al.*, 1988; Wang and Simoneit, 1990; Stout, 1992; Ming *et al.*, 1994; Bechtel *et al.*, 2002). High-molecular-weight *n*-alkanes (viz. *n*-$C_{21}$ to *n*-$C_{35}$, with *n*-$C_{27}$, *n*-$C_{29}$ and *n*-$C_{31}$ predominance) are most likely derived from cuticular waxes in higher plants (Eglinton and Hamilton, 1967; Tissot and Welte, 1984; Philp, 1985; Hazai *et al.,* 1988; Wang and Simoneit, 1990; Peters and Moldowan, 1993; Table 2.6).

Carbon preference index (CPI) values in brown coals range between 1 and 18, but mostly fall between 6 and 10 (Chaffee and Johns, 1985; Stout, 1992; Hazai *et al.,* 1988; Ming *et al.*, 1994; Schulze and Michaelis, 1989). Variations in *n*-alkane distribution, CPI and abundance with coal type have been observed (Hagerman and Hollerbach, 1979; Chaffee and Johns, 1985; Winkler, 1986; Stefanova *et al.,* 1995). Although the patterns do not always appear consistent, elevated *n*-alkane concentrations are common in the paler lithotypes.

Acyclic isoprenoids are infrequently reported in brown coals and represent minor constituents. Compounds recognised include $C_{15}$-$C_{20}$ regular isoprenoids including pristane and phytane and irregular $C_{20}$ head to head linked isoprenoids (Wang and Simoneit, 1990).

#### 2.3.2.2 Sesquiterpenoids

Sesquiterpenoids are widely distributed in higher plants, are ubiquitous in resins and essential oils, but are only occasionally reported in coals (Hagerman and Hollerbach, 1979; Grantham and Douglas, 1980; Simoneit *et al.,* 1986; Sunay and Gaines, 1989; Li *et al.,* 1990; Wang and Simoneit, 1990; Bechtel *et al.*, 2002; Bechtel *et al.*, 2004). Grantham and Douglas (1980) suggested their sparsity in coals may be due to losses associated with weathering (due to their relatively low molecular weight), or to their diagenetic transformation to more stable aromatic compounds. Sesquiterpenoids in coals are primarily derived from gymnosperm resins (Chaffee *et al.,* 1986) and some specific chemotaxonomic associations have been postulated (Grantham and Douglas, 1980; Otto *et al.*, 1997).

Sesquiterpenoids ranging from $C_{13}$ to $C_{15}$ have been detected in brown coals, with the latter typically being the most common. This family of compounds exhibits considerable diversity with members of the cadinane series, together with eudesmane and the cadalene series (Figure 2.6) being the most frequently reported. Few correlations between sesquiterpenoids and coal type have been established and the results of previous studies appear somewhat inconsistent. However, the pale and woody lithotypes (especially those with significant resinite contents) do tend to exhibit elevated sesquiterpenoid abundances (Hagemann and Hollerbach, 1980; Simoneit *et al.,* 1986; Ming *et al.*, 1994).

#### 2.3.2.3 Diterpenoids

Diterpenoids are common in brown coals (Hagerman and Hollerbach, 1979; Chaffee, 1981; Noble *et al.,* 1986; Simoneit *et al.*, 1986; Winkler, 1986; Wang and Simoneit, 1990; Ming *et al.*, 1994; Bechtel *et al.*, 2002; Bechtel *et al.*, 2004). However, they characteristically show considerable diversity in abundance and composition between coal types. Tricyclic and

tetracyclic diterpenoids (Figure 2.6) are abundant in higher plants (Noble *et al.*, 1986) and are an important constituent of conifer resins (Chaffee, 1981; Simoneit *et al.*, 1986; Noble *et al.*, 1985; Noble *et al.*, 1986; Alexander *et al.*, 1988; Grimalt *et al.*, 1988; Hazai *et al.*, 1989; Weston *et al.*, 1989; Otto *et al.*, 1997) and leaf waxes (Killops *et al.*, 1995). Several diterpenoid compounds have been suggested as biomarkers for specific conifer families (Noble *et al.*, 1985; Noble *et al.*, 1986; Otto *et al.*, 1997). However, there does not appear to be a broad consensus on their specificity and some workers have cautioned against their use in palaeoecological reconstructions (Schulze and Michaelis, 1989; Disnar and Harounda, 1994).

Common brown coal diterpenoid assemblages include mixtures of pimarane and abietane (tricyclic) and phyllocladane and kaurane (tetracyclic) (Chaffee, 1981; Livsey *et al.*, 1984; Noble *et al.*, 1986; Winkler, 1986; Wang and Simoneit, 1990; Ming *et al.*, 1994; Table 2.6). Unsaturated rimuenes have also been noted in low concentration.

While numerous workers have identified resin as a key diterpenoid source, relationships between resinite and compound abundance do not appear consistent. Sheng *et al.* (1992) and Ming *et al.* (1994) noted a poor correlation between the two, although increased diterpane abundance in woody coals is commonly reported (Hagemann and Hollerbach, 1980; Weston *et al.*, 1989 and references therein; Bechtel *et al.*, 2004).

#### 2.3.2.4 Non-hopanoid triterpenoids

Pentacyclic triterpanes with a non-hopanoid structure are commonly reported in Tertiary brown coals and include members of the oleanane, lupane, ursane, fernane, friedelane, bicadinane and taraxastane families (Figure 2.6). Of these, the oleanoids, ursanoids, and lupanoids are indicative of organic matter derived from higher plants. In particular, they typify angiosperm inputs and, more specifically, their epicuticular waxes (Chaffee *et al.*, 1986; Wang and Simoneit, 1990; Stout, 1992; Peters and Moldowan, 1993; Moldowan *et al.*, 1994; Killops *et al.*, 1995; Peters *et al.*, 2004), while fernenes are abundant in ferns, mosses and lichens. Terrigenous triterpenoids are not ubiquitous within brown coals (Del Rio *et al.*, 1992) and a link between their abundance and post- depositional marine influence has been postulated (Norgate *et al.*, 1977; Murray *et al.*, 1997).

The most widely occurring terrigenous triterpenoids with intact skeletons are the oleanenes and ursenes and, to a lesser extent, the lupenes and fernenes (Hagemann and Hollerbach, 1980; Chaffee, 1981; Winkler, 1986; Wang and Simoneit, 1990; ten Haven *et al.*, 1992b; Stout, 1992; Killops *et al.*, 1995; Stefanova *et al.*, 1995; Murray *et al.*, 1997). Variations in abundance of the terrigenous triterpenoids are not well understood and significant changes in abundance have been noted within and between individual coal types (Chaffee, 1981).

However, higher concentrations of oleanenes and ursenes have been noted in woody coals (Hagemann and Hollerbach, 1980) and certain liptinite-rich coals (Chaffee, 1981; Winkler, 1986).

Modified terrigenous triterpenoids in which the A-ring has been cleaved, or reduced to five members (Des-A and A-ring contracted triterpenoids, respectively: Figure 2.6) may occur in brown coals. Des-A triterpenoids have been reported (Chaffee, 1981; Wang and Simoneit, 1990; Stout, 1992; Killops *et al.*, 1995) and are thought to be derived from $C_{30}$ counterparts (Weston *et al.*, 1989; Stout, 1992; Woolhouse *et al.*, 1992; Ming, 1994; Killops *et al.*, 1995) by microbially-mediated loss of ring A during early diagenesis (Trendel *et al.*, 1989; Stout, 1992). Precursors for des-A compounds occur in numerous angiosperm genera and their use as a marker for angiosperm input has been suggested (Weston *et al.*, 1989; Stout, 1992, Killops *et al.*, 1995). Although commonly detected in brown coals, they are rarely assigned to specific compound classes. Of those that have been identified, compounds with lupane, oleanane and ursane skeletons are the most often reported (Chaffee, 1981; Wang and Simoneit, 1990; Stout, 1992; Stefanova *et al.*, 1995). Their variation with coal type is not well known, although Chaffee (1981) reported an association with liptinite-rich lithotypes. The precise mechanism for formation of A-ring contracted triterpenoids is unclear (ten Haven *et al.*, 1992a) and these compounds are generally considered to be rapidly-transformed diagenetic intermediates (Killops and Frewin, 1994). Reports of A-ring contracted compounds in brown coals are few and relate to oleanane- and ursane-derived structures (ten Haven *et al.*, 1992a).

#### 2.3.2.5 Hopanoids

Hopanoids are widespread within all sediments (Quirk *et al.*, 1984) and are mostly of bacterial origin (Waples and Machihara, 1991). Hopanes with extended side-chains on the E-ring are entirely derived from prokaryotic organisms, especially eubacteria (Chaffee *et al.*, 1986). Biomarker investigations of various brown coals have identified essentially the same suite of hopanoids, in which both unsaturated (hopene) and saturated (hopane) species are present. Their stereochemistries in order of decreasing frequency are: biological 17β,21β and more thermodynamically stable 17β,21α and 17α,21β configurations (Hagemann and Hollerbach, 1980; Chaffee, 1981; Winkler, 1986; Hazai *et al.*, 1988; Wang and Simoneit, 1990; Stout, 1992; ten Haven, 1992a; Ming *et al.*, 1994; Bechtel *et al.*, 2002; Figure 2.6). Degraded hopanoids are occasionally recognised, including the 17,21-secohopane and 8,14-secohopane series (Stefanova *et al.*, 1995).

The most abundant hopanoid in brown coal is commonly 22R-17α(H),21β(H)-homohopane and investigations of this compound by Quirk *et al.* (1984) found it occurred at the very

earliest stage of diagenesis. Hop-17(21)-ene, 17β(H)- 22,29,30-trisnorhopane and 17α(H),21β(H)-norhopane can also occur in significant concentrations.

Variations in hopanoid abundance with coal type have been recognised, although once again the results are somewhat inconsistent. Increasing homohopane from light to dark coals (Winkler, 1986), and its enrichment in the dark high-mineral varieties (Hagemann and Hollerbach, 1980; Chaffee, 1981) has been used to infer increased bacterial activity and more intense anaerobic decomposition, respectively. Contrary tends in hopanoid abundance were reported by Ming *et al.* (1994), with the highest levels in pale coals, while Bechtel *et al.* (2004) noted the highest levels in wood-rich forest swamp coals and sapropelic varieties. Bechtel *et al.* (2004) also reported a correlation between hopanes and gelification and considered this a measure of degradation by aerobic bacteria, while hop-17(21)-ene was thought to reflect the activity of anaerobic bacteria.

#### 2.3.2.6 Steroids

Sedimentary steroids are sourced from the sterols synthesised by higher plants and algae (Waples and Machihara, 1991) and undergo modification via various microbial and chemical reactions during diagenesis and catagenesis (Philp, 1985). The $C_{29}$ steranes and diasteranes (Figure 2.6) in coals reflect the higher plant input to the peat bog (van Aarssen *et al.*, 1996). Steroids are uncommon in brown coals and their occurrence is generally restricted to diasterenes (Chaffee, 1981; Petrov *et al.*, 1985; Winkler, 1986; Wang and Simoneit, 1990), although some regular steranes have also been reported (Chaffee, 1981; Hazai *et al.,* 1988; Curiale and Lin, 1991; Lu and Kaplan, 1992). Where both occur, the former are typically the more abundant.

The distribution of steroids within brown coals appears erratic. Working on Victorian coals, Chaffee (1981) found that diasterenes are restricted to the medium dark and pale lithotypes while steranes are limited to the pale lithotype. In contrast, Winkler (1986) found diasterenes to be more prevalent in the dark lithotypes of the Helmstedt deposit. Stefanova *et al.* (1995) detected regular steranes in telovitrinite-rich Bulgarian lignites, whereas both diasterenes and steranes were evident in the associated detrovitrinite-rich lithotypes.

### 2.3.3 Inorganic constituents

Brown coal contains a variety of inorganic components including water, dissolved salts, exchangeable ions, organometallic complexes and crystalline minerals (Kiss and King, 1977, 1979; Black, 1982; Brockway and Higgins, 1991; Brockway *et al.*, 1991; Quast and Readett,

1991; Ward, 1992, 2002). High moisture contents and oxygen-rich functional groups impart ion exchange properties to the coal, resulting in significant quantities of water-soluble and ionic species, respectively (Durie and Swaine, 1971; Kiss and King, 1977; Brockway *et al.*, 1991; Schafer, 1991). Consequently, crystalline minerals may represent only a moderate portion of the total inorganic fraction of a brown coal (Higgins *et al.*, 1980, Readett and Quast, 1987).

Inorganic matter may be incorporated into coals from the time of peat accumulation to the present. Four distinct phases of mineralisation are possible: syngenetic, early diagenetic, late diagenetic and epigenetic (Davis *et al.*, 1984; Ward, 1986, 2002; Table 2.7). Of these, the former is particularly useful for palaeoenvironmental evaluation.

Table 2.7 Phases and types of coal mineralisation

| Phase and Timing | Mineralisation and Source | Mineral Matter Type |
|---|---|---|
| SYNGENETIC (pre-burial) | (i) Inherent inorganic - from plants | Ca, K, Si |
| | (ii) Detrital mineral - washed or blown in | Quartz, kaolinite |
| | (iii) Authigenic mineral - ions in swamp water | Kaolinite, pyrite, marcasite, sulphur |
| | (iv) Bioturbation - at seam roofs | Quartz and kaolinite |
| EARLY DIAGENETIC (minor burial) | Authigenic mineral - interaction of sulphate-rich waters with peat | Pyrite, marcasite, organic sulphur |
| LATE DIAGENETIC (major burial and rank advance) | Authigenic mineral - precipitation in fissures | Pyrite, marcasite, gypsum, barite |
| EPIGENETIC (recent) | Ion and water migration - from aquifers | NaCl, Ca, Mg, Fe |

### 2.3.3.1 Syngenetic constituents

Syngenetic minerals incorporated during peat accumulation may arise from mineral matter in the precursor vegetation, authigenic processes, adventitious co-deposited sediment from external sources and that introduced by bioturbation at seam interfaces (Diessel, 1980, 1992; Ward, 1986, 2002; Wust *et al.*, 2002). The proportion of inherent mineral to total inorganic content is very low and this material is largely taken into solution, or depleted by micro-organisms following burial (Cohen *et al.*, 1987). Adventitious matter may be introduced into the peat as detrital grains deposited by wind or water, or volcanic processes and is typically the most abundant and long lasting. The distribution of syngenetic mineral varies with respect to seam margins. Vegetation around the swamp margins and ombrotrophic mine development may prevent clastic sediment reaching the peat, while acid swamp waters can cause flocculation of clays and other suspended particles, thereby limiting their dispersal (Staub, 1991; Ward, 2002).

Quartz and kaolinite are typically the most abundant syngenetic minerals. However, many others including feldspar, detrital clay minerals (e.g. montmorillinite, illite and chlorite), muscovite, bauxite, heavy minerals such as rutile and zircon and the sulphides pyrite and marcasite can be incorporated during this phase (Black, 1982; Ward and Swaine, 1995; Ward, 2002).

Kaolinite is the dominant clay mineral in many coals (Diessel, 1980; Davis *et al.*, 1984; Miller and Given, 1985; Ward, 1986) and is the main authigenic mineral in most tropical peats (Wust *et al.*, 2002). Kaolinite has a preference for neutral to slightly acid environments and its dominance may relate to its greater stability relative to other clays within the acid peat environment (Miller and Given, 1985; Manuel and Quast, 1990; Diessel, 1992). Both detrital and authigenic kaolinite have been reported, the latter involving leaching of Al under low pH conditions and precipitation of the clay in areas of higher pH (Ward, 2002). Quartz occurs mainly as angular, detrital particles, although microcrystalline (i.e. <10 μm) authigenic quartz may also form and can be prominent in intervals of very low mineral abundance (Readett and Quast, 1990; Ward, 1992, 2002). Pyrite and marcasite form by authigenic means from the interaction of $H_2S$ and dissolved iron (Ward, 2002).

Minerals such as quartz and kaolinite are unaffected by water and ionic migration within brown coals (George *et al.*, 1984) and their total abundance and relative composition have been widely applied to infer depositional setting (Hacquebard and Donaldson, 1969; Shibaoka, 1972; Davis *et al.*, 1984; Cohen *et al.*, 1987; Tadros, 1988; Moore, 1989; George and Mackay, 1991; Diessel, 1992; Diessel and Smyth, 1995; Ward and Swaine, 1995). These parameters variously reflect the tectonic stability and intensity of mechanical erosion in the hinterland and the resulting detrital input; swamp conditions (i.e. ombrogenous versus topogenous); proximity to active fluvial sedimentation; and the height of the water table. In general, deeper waters, more stable conditions and ombrogenous settings favour kaolinite, while quartz increases with mechanical erosion and proximity to active sedimentation, and in topogenous settings.

Quartz and kaolinite concentrations can also vary significantly, both vertically and laterally, within seams and are particularly sensitive to the proximity of clastic sources, as represented by seam splits and margins (Ferm and Staub, 1984; Esterle and Ferm, 1986; Hagelskamp *et al.*, 1988; Ward and Swaine, 1995). High mineral contents also are common in the basal parts of seams where they are reflect the progression from herbaceous aquatics to hardwood communities and a corresponding decrease in mineral influx as the low-lying depressions become colonised by forests (Raymond *et al.*, 1987). High basal mineral has also been interpreted as reflecting a combination of contemporaneous organic and inorganic sedimentation as peat formation commenced and mixing due to bioturbation (Davis *et al.*, 1984). In contrast, very low mineral contents are characteristic of ombrogenous settings from

which clastic input is largely excluded (Moore, 1989; Anderson and Mackay, 1990; Diessel, 1992).

#### 2.3.3.2 Diagenetic and epigenetic constituents

During early burial of peat, authigenic minerals form by a variety of biological or chemical processes, commonly in joints and fissures (Cohen *et al.*, 1987; Ward, 2002). Such authigenic mineral matter may also occur as nodules or replacement of wood, or as sand and clay dykes where clastic sediment has been mobilised from overlying strata (Ward and Swaine, 1995). The final phase of brown coal mineralisation is driven by groundwater percolation and ion migration out of adjacent aquifers (Kiss and King, 1979; Brockway and Borsaru, 1985; Cohen *et al.*, 1987; Ward and Swaine, 1995). This process results in the introduction of silica and assorted ions including sodium, chlorine, calcium, magnesium, iron and aluminium (Hodges *et al.*, 1983) and commonly results in well developed vertical concentration gradients (Brockway and Borsaru, 1985).

#### 2.3.3.3 Sulphur

Sulphur levels vary significantly in coals and several workers have noted a close association between overlying marine sediments and high-sulphur coals (Williams and Keith, 1963; Westgate and Anderson, 1984; Cohen *et al.*, 1984; Gavett and Ferm, 1985; Kiss *et al.*, 1985; Casagrande, 1987; Teichmuller, 1989). Increases in the sulphur content of coal seams toward laterally contiguous marine sediments have also been reported (Ferm and Staub, 1984; Holdgate *et al.*, 2000).

Sulphur levels are controlled by a number of factors including sulphate availability, the biochemical and physical state of plant matter in the peat and the duration of exposure of the peat to sulphate-rich waters (Westgate and Anderson, 1984; Given and Miller, 1985). To a large extent, these are determined by marine proximity and regional sedimentary conditions combined with peat reactivity. Marine waters provide an extensive sulphur source, while elevated pH in marine waters facilitates bacterial reduction of its dissolved sulphate (Styan and Bustin, 1984). The nature of the overlying sediments, in particular their permeability (Kravitis and Crelling, 1981), and proximity to vertical seam boundaries in areas removed from marine influence (Kiss *et al.*, 1985) are other significant controls on sulphur abundance in brown coal.

## 2.4 TERTIARY COALS OF SOUTHERN AUSTRALIA

### 2.4.1 Occurrence and distribution

Coal formation was widespread during the Middle to Late Eocene in basins along the southern Australian continental margin (Hunt, 1982; Johnson, 1995; Holdgate *et al.*, 2000; Holdgate and Clarke, 2000; Figure 2.7). Thick coals also formed during the Middle Miocene, although they are significantly more restricted in distribution. Many of these brown coal deposits show gradual transitions from non-marine to marine conditions and occur in either graben-like depressions, embayments bound by barrier sands, or incised palaeovalleys. Johnson (1995) noted that the Eocene deposits typically comprise thin (<150 m) sequences of fluvial sands interbedded with coal in both major seams (10 to 30 m thick) and minor seams (1 to 2 m), while the Miocene seams are thicker (30 to 130 m) and represent a significant part of the total sedimentary succession.

Throughout the Tertiary sedimentary record of southern Australia a close correlation exists between peat formation and peak periods of coastal onlap, coupled with frequent sea level oscillations and optimum climatic (i.e. subtropical) conditions (Holdgate *et al.*, 1995; Holdgate and Clarke, 2000). Extensive development of ombrogenous conditions has also been postulated (Crosdale, 1993; Holdgate *et al.*, 1995; Holdgate and Clarke, 2000). Thicker coals, such as those in the Gippsland Basin, are interpreted to have formed during highstands, while thinner deposits such as those of the St. Vincent and Bremer Basins were interpreted as early transgressive system tract deposits (Holdgate *et al.*, 1995; Holdgate and Clarke, 2000).

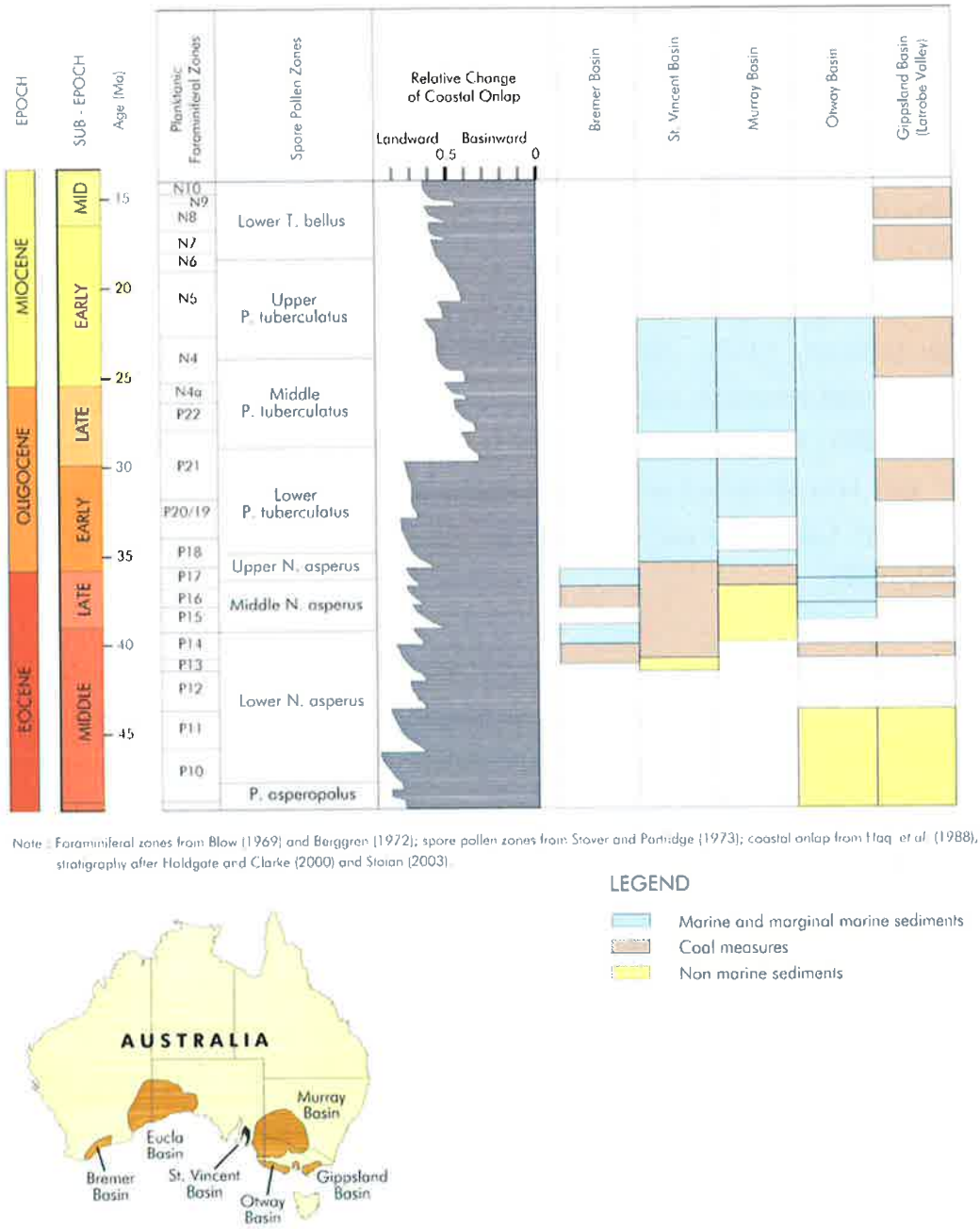



Figure 2.7 Southern Australian brown coal deposits

### 2.4.2 Conditions for accumulation and preservation

Southern Australian Tertiary coal development was closely related to the prevailing tectonic and climatic conditions, which led to widespread basin development (sites for accumulation and preservation) and luxuriant vegetation (abundant source material), respectively. As rifting between the Australian and Antarctic continents increased, extensive terrestrial and paralic sedimentation occurred along the passive continental margin by the Mid Eocene

(Alley and Lindsay, 1995). This was accompanied by significant tectonic activity resulting in locally down-faulted or down-warped areas.

Although some cooling occurred in the Middle to Late Eocene associated with bridging of the South Tasman Rise and development of a circum-polar current (Kemp, 1981; Alley, 1991; Macphail *et al.*, 1994; White 1998), climatic conditions were characterised by high rainfall and humidity (Meakin, 1985; Manuel, 1988). Precipitation in the order of 2000 mm and a mean annual temperature of approximately 15 to 21°C have been suggested (Christophel, 1994; Rowett, 1997; Holdgate and Clarke, 2000), with essentially no seasonality of rainfall or temperature (Manuel, 1988). These conditions led to the development of non-seasonal, subtropical to warm temperate rainforest over much of the continent (Macphail *et al.*, 1994; Brakel *et al.*, 1995; Alley and Lindsay, 1995), providing abundant organic matter for peat formation. Key taxa identified as making a dominant contribution to extant flora during the Eocene included *Casuarinaceae*, *Proteaceae*, *Podocarpaceae*, *Fagaceae* and *Lauraceae* (Christophel, 1989).

High rainfall led to replacement of the deep chemical weathering which typified the Late Cretaceous and Early Tertiary with conditions favouring mechanical erosion in the Middle to Late Eocene (Brakel *et al.*, 1995). The cumulative effect was active drainage, terrestrial sedimentation and development of numerous swamp settings suitable for peat accumulation and burial. Holdgate and Clarke (2000) highlighted the significance of long-standing barrier systems for isolation and protection of coastal peat swamps and Holdgate *et al.* (2000) noted a relationship between peat thickening and local tectonics.

By the Early Oligocene, cooling coinciding with a major fall in global sea level, a seasonal rainfall pattern and periods of dryness combined to limit coal formation (Kemp, 1981; Alley and Lindsay, 1995; Brakel *et al.*, 1995). From the Miocene onwards the continent has been situated between the high rainfall belts of the Southern Ocean and the equatorial zone, further restricting widespread peat accumulation (Brakel *et al.*, 1995).

### 2.4.3 Coal types and characteristics

Australian Tertiary coals are characteristically vitrinite-rich and inertinite-poor, with variable liptinite contents (George, 1975, 1982; Smyth and Harrison, 1976; Hunt, 1982; Johnson, 1995). George (1975, 1982) recognised five basic lithotypes from the Latrobe Valley, Gippsland Basin (Table 2.8).

Table 2.8 Latrobe Valley lithotypes (after George, 1975, 1982)

| Lithotype | Colour | Tissue Concentration | Tissue Size | Gelification |
|---|---|---|---|---|
| Dark | Black to dark brown | High | Mainly <25 cm and groundmass most prominent | High |
| Medium dark | Dark brown | Moderate to high | Mostly large (>25 cm), woody | Variable (slight) |
| Medium light | Medium brown | Variable (low to high) | Typically very large (>50 cm) | Low |
| Light | Light brown | Low | Small groundmass | Minor |
| Pale | Yellow brown | Very low | Small groundmass | Minor |

Latrobe Valley coals comprise vitrinite (70 to 95%), with moderate amounts of liptinite (2 to 25%) and very low inertinite (1 to 3%: George 1975, 1982). Within the vitrinite fraction, detrovitrinite predominates (50 to 70%) and the coals are typically poorly gelified with attrinite most abundant. Telovitrinite ranges from approximately 10 to 30% and is composed mainly of texto-ulminite, with some textinite and eu-ulminite, while gelovitrinite ranges from approximately 2 to 12%. Of the intact liptinites, sporinite, cutinite, resinite and suberinite are widespread, but typically occur in relatively low abundance (i.e. less than 3%). Liptodetrinite also occurs at a similar concentration. Inertinites are rare and include funginite, fusinite, semifusinite and inertodetrinite. Several of the maceral parameters vary with lithotype, especially liptinite, which increases from dark to pale varieties and may be highly enriched in the latter (i.e. up to approximately 25%). Detrovitrinite also increases from dark to pale coal at the expense of telovitrinite. Fusinite abundance and gelification are greatest in the darker lithotypes (Holdgate *et al.*, 2000).

Coals from the northern St. Vincent Basin Coalfield examined by Smyth and Harrison (1976) were found to be vitrinite dominated, with moderate liptinite (approximately 10%) and low inertinite (approximately 1%). These authors noted petrographic similarities to other Australian Tertiary coals.

## 2.5 SUMMARY

Coal formation is a complex process in which the factors determining coal type are numerous and interrelated. They include the precursor vegetation, its degree of biochemical modification by bacteria and fungi, the position of the groundwater table the mode of accumulation of organic matter, and the hydrogeochemistry of the swamp. Causal relationships between the depositional setting of a coal and its petrographic characteristics are evident, although considerable variation is possible. Progressive petrographic changes upward through seams are common and reflect changes in the local palaeoenvironment.

Coal formation since the Mid Tertiary has been widespread in passive continental margin settings along the southern Australian seaboard, under warm and wet climatic conditions,

corresponding to periods of peak sea level. The resultant coals are predominantly vitrinite rich and inertinite poor. Various models for brown coal lithotype formation have been proposed, with source material and the biomechanical conditions during accumulation identified as key factors. Eustasy and climatic controls over groundwater levels were also highlighted as significant in determining lithotype and forming lightening-up sequences within seams.

Several systems have been developed for brown coal identification and differentiation, each involving either macropetrographic (i.e. lithotype) or micropetrographic (i.e. maceral) criteria, or a combination of the two. Lithotype classifications commonly are based on texture and colour, while maceral-based schemes focus on the presence, degree of oxidation, gelification and tissue preservation of individual macerals.

Biomarkers and mineral constituents provide an additional dimension to the palaeoenvironmental interpretation of brown coals. Biomarker groups detected in brown coals include *n*-alkanes, acyclic isoprenoids, sesquiterpenoids, diterpenoids, intact and modified non-hopanoid triterpenoids, hopanoids and steroids. Most of these biomarkers are derived from terrestrial organic matter, allowing broad differentiation into gymnosperm and angiosperm groupings. Others may be used to assess the level of bacterial contribution. Inorganic constituents of brown coals include water-soluble salts and crystalline minerals. Quartz and kaolinite are the dominant minerals and their respective abundance can be related to the regional depositional setting and swamp conditions.

# 3 METHODOLOGY AND ANALYTICAL PROCEDURES

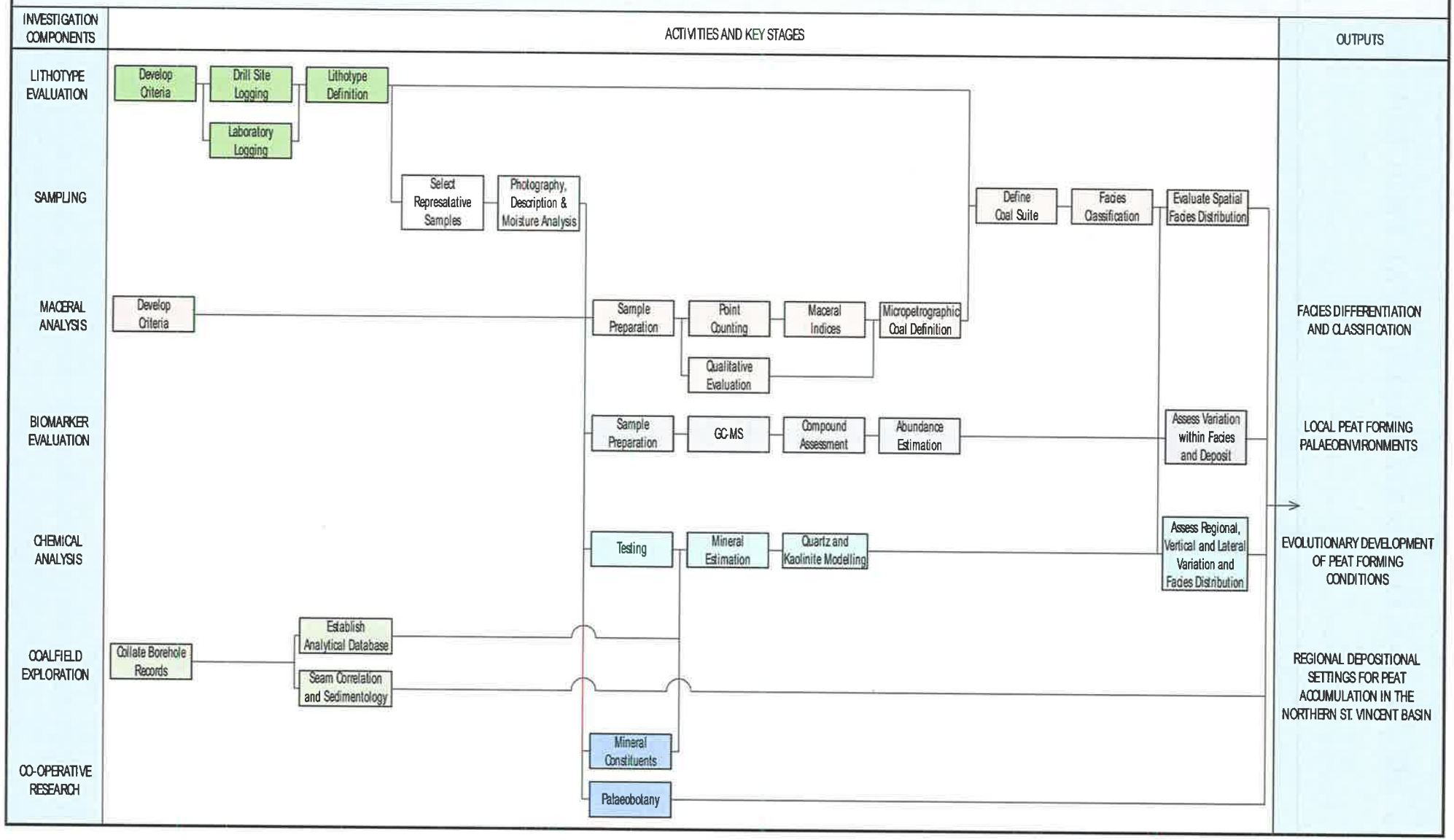
A multidisciplinary research program involving four major phases of data gathering was developed to evaluate the coals of the Lochiel and Bowmans Deposits. These include lithotype, maceral, biomarker and inorganic assessments of representative samples collected during the project. In addition, pre-existing borehole data from coalfield exploration in the region was evaluated and co-operative research programs initiated covering palaeobotany, palynology and mineralogy. An overview of the project methodology is shown schematically in Figure 3.1.

The project methodology and, in particular, the data collection and analytical procedures are the focus of this chapter. Data evaluation techniques developed specifically for this project are also outlined. More detailed information on some procedures is presented in various Appendices (Table 3.1).

Table 3.1 Supporting information on analytical procedures presented in appendices

| Appendix Location | Subject | Procedure |
|---|---|---|
| Appendix C1 | Maceral evaluation | Sub-maceral definition |
| Appendix D3 | Biomarker evaluation | Relative Concentration Index (RCI) derivation |
| Appendix E1 | Mineral evaluation | Quartz and kaolinite estimation |

**Figure 3.1 Research project methodology**



## 3.1 DATA AVAILABILITY AND GATHERING

Coals of the northern St. Vincent Basin are not exposed at the surface and are typically covered by in excess of 40 m of sediment. Samples for the current research were obtained in conjunction with coalfield evaluation drilling investigations undertaken by the Electricity Trust of South Australia (ETSA). These programs covered both the Lochiel and Bowmans Deposits, although the drilling intensity was greatest at Lochiel, leading to enhanced coverage in this deposit, particularly with respect to lithotype evaluation. Data acquisition proceeded sequentially commencing with lithotype assessment (Table 3.2).

Table 3.2 Lithotype logging summary

| Deposit | Borehole | Depth Range (m) | Seams | Field Log[i] | Laboratory[ii] |
|---|---|---|---|---|---|
| Lochiel | V634 | 37.1 - 54.0 | F, G, H | √ | |
| Lochiel | V661 | 26.4 - 32.4 | G | √ | |
| Lochiel | V662 | 17.9 - 26.6 | G | √ | √ |
| Lochiel | V670 | 32.0 - 38.4 | G | √ | √ |
| Lochiel | V672 | 34.5 - 43.3 | (F), G | √ | √ |
| Lochiel | V673 | 20.8 - 28.2 | G | √ | |
| Lochiel | V674 | 25.8 - 33.0 | G | √ | √ |
| Lochiel | V675 | 27.0 - 34.2 | G | √ | |
| Lochiel | V679 | 50.5 - 65.2 | F, G, H | √ | |
| Lochiel | V690 | 44.8 - 59.0 | F, G, H | √ | |
| Lochiel | V691 | 42.2 - 55.8 | F, G, H | √ | |
| Lochiel | V692 | 16.5 - 23.5 | G | √ | |
| Lochiel | V693 | 29.0 - 39.5 | G | √ | |
| Lochiel | V694 | 41.8 - 56.0 | F, G, H | √ | |
| Lochiel | V695 | 39.4 - 53.4 | F, G, H | √ | |
| Lochiel | V701 | 51.3 - 65.5 | F, G, H | √ | |
| Lochiel | V702 | 35.7 - 45.3 | (F), G | √ | |
| Lochiel | V703 | 58.2 - 68.0 | G, H | √ | |
| Lochiel | V704 | 58.0 - 74.0 | F, G, H | √ | |
| Lochiel | V705 | 58.4 - 75.5 | F, G, H | √ | |
| Lochiel | V706 | 55.0 - 69.5 | F, G, H | √ | √ |
| Lochiel | V707 | 49.8 - 64.6 | F, G, | √ | |
| Lochiel | V714 | 53.5 - 70.3 | F, G, H | √ | |
| Lochiel | V715 | 46.0 - 70.0 | F, G, H | √ | |
| Lochiel | V716 | 30.6 - 40.0 | (F), G | √ | |
| Lochiel | V717 | 33.5 - 41.0 | (F), G | √ | |
| Lochiel | V723 | 36.2 - 45.5 | (F), G | √ | |
| Lochiel | V724 | 32.8 - 40.0 | G | √ | |
| Lochiel | V725 | 34.5 - 43.8 | G, H | √ | |
| Lochiel | V726 | 31.8 - 48.7 | F, G, H | √ | |
| Lochiel | S12 | 0.0 - 6.2 | G | √ | |
| Lochiel | V749 | 53.8 - 63.0 | G | √ | |
| Bowmans | B5 | 69.2 - 91.2 | B1, B3, C | √ | |
| Bowmans | B28 | 62.8 - 94.2 | B1, B3, C | √ | |
| Bowmans | V320 | 75.0 - 93.5 | B3, C | | √ |
| Bowmans | V321 | 66.8 - 89.0 | B1, B3, C | | √ |
| Bowmans | V336 | 75.5 - 93.0 | B3, C | | √ |

.../continued on p. 48

Note: Bracketed seam name (i.e. (F)) indicates tentative seam correlation. i – indicates logging at the drill site under field conditions; ii – indicates logging at a core library under laboratory conditions.

Borehole logs and chemical analysis from ETSA's coalfield exploration were also made available to the author.

Following lithotype logging samples of macroscopically defined coal varieties were selected for more detailed investigation. Evaluation became progressively more focused as the study proceeded through micropetrographic, inorganic and biomarker assessments, with a tendency towards testing of representative samples as the understanding of coal varieties and their distribution improved. The sampling and analytical program is summarised in Table 3.3 and detailed in Appendix A.

Table 3.3 Sampling and testing summary

| Sample Location | Testing Undertaken | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lithotype | | Maceral | | Chemical | | | Biomarker | | | |
| Deposit / Hole | Descr-iption | Photo-graph | Descr-iption | Point Count | Suite A | Suite B | Qz | Yield | GC-MS | Min-eral | Palaeo-botany |
| **Lochiel** | | | | | | | | | | | |
| V662 | 1 | 1 | 1 | | | | | | | | |
| V666 | 1 | 1 | 1 | | 1 | 1 | | | | | |
| V672 | 22 | 21 | 22 | 2 | 20 | 20 | | 1 | 1 | 2 | |
| V673 | 1 | | 1 | | | | | | | | |
| V674 | 17 | 17 | 17 | 2 | 7 | 7 | | 1 | 1 | 2 | 2 |
| V675 | 3 | 3 | 3 | | 2 | 2 | | | | | |
| V690 | 9 | 7 | 9 | 2 | 5 | 4 | | 1 | 1 | 3 | |
| V691 | 3 | 3 | 3 | | | | | | | 2 | |
| V692 | 3 | 2 | 3 | | | | | | | | |
| V694 | 1 | 1 | 1 | | 1 | | | | | | |
| V695 | 1 | 1 | 1 | 1 | | | | | | 1 | |
| V701 | 3 | 3 | 3 | | 3 | 2 | | | | | |
| V703 | 5 | 5 | 5 | | 1 | 1 | | | | | |
| V704 | 45 | 11 | 21 | 20 | 24 | 24 | 24 | 2 | 2 | 23 | |
| V705 | 3 | 2 | 3 | | 1 | | | | | | |
| V706 | 9 | 9 | | 9 | 9 | 9 | | 1 | 1 | 2 | |
| V707 | 2 | 2 | 2 | | 1 | 1 | | | | | |
| V714 | 28 | 28 | 28 | 28 | 28 | 28 | | 9 | 9 | 28 | 6 |
| V715 | 2 | 1 | 2 | | | | | | | | |
| V716 | 1 | | 1 | | | | | | | | |
| V723 | 3 | 3 | 3 | | 3 | 3 | | 1 | 1 | | |
| V724 | 2 | 1 | 2 | | 1 | | | | | | |
| S12 | 16 | 15 | 15 | 14 | 16 | 16 | | | | 1 | 8 |
| *Total* | *181* | *137* | *147* | *78* | *123* | *118* | *24* | *16* | *16* | *64* | *16* |
| **Bowmans** | | | | | | | | | | | |
| B5 | 34 | 13 | 34 | 34 | 34 | 34 | 23 | | | 20 | 2 |
| B28 | 53 | 53 | 53 | 53 | 53 | 53 | 31 | 11 | 11 | 42 | 9 |
| *Total* | *90* | *66* | *87* | *87* | *87* | *87* | *54* | *11* | *11* | *62* | *11* |

Key: Suite A chemical testing includes proximate analysis (ash, volatile matter, moisture, fixed carbon), total sulphur and ash analysis ($Fe_2O_3$, $Al_2O_3$, $SiO_2$, MgO, CaO, $K_2O$, $Na_2O$, $SO_3$, $TiO_2$).
Suite B chemical testing includes ultimate analysis (C, H, N, O, S), forms of sulphur (organic, pyritic, sulphate), inorganics (Na, Cl) and acid soluble inorganics (Fe, Al, Si, Mg, Ca, K).
Qz denotes quartz analysis.
Co-operative research included mineral investigation (SEM/EDS, XRD) and palaeobotanical studies (palynology, cuticular analysis).

## 3.2 LITHOTYPE EVALUATION

Macropetrographic assessment of coal lithotypes was undertaken principally using core samples, although two seam exposures were also briefly available in trial pit excavations. Lithotype evaluation provided a relatively rapid, non-destructive and continuous measurement of coal characteristics and was suitable for routine application to coalfield exploration boreholes. The resulting lithotype logs provided an extensive data set for evaluation of coal properties and were used to select samples for further investigation.

### 3.2.1 Field lithotype evaluation

The initial evaluation of lithotypes was undertaken on 100 mm-diameter drill cores. Investigation at multiple sites was possible, with thirty-two boreholes logged in the Lochiel Deposit and two in the Bowmans Deposit, respectively (Table 3.2; Figures 3.2 and 3.3). Sites were selected to maximise deposit coverage and correlation. The drill sites at Lochiel focused on the central and southern portions of the Lochiel Deposit whereas those at Bowmans targeted the northern and central regions of the Bowmans Deposit. In both deposits the boreholes sampled are located in zones of maximum coal accumulation.

Logging of core was undertaken at the drill site immediately after its removal from the barrel, allowing its description at in situ moisture levels. Examination of fresh core also minimised other post-recovery modification. Initial steps involved determination of recovery, storage and cleaning. Core was usually retrieved in 3 m runs, measured, placed in 1 m PVC split tubes and labelled for depth below surface. In general, coal zones were fully recovered. Where core loss occurred, but could not be accurately positioned, the missing interval was assigned to the end of the drilling run. In some instances this was later adjusted using borehole geophysical logs, particularly where core losses occurred in clastic intervals. Prior to lithotype logging drilling mud was scraped from the core surface to fully expose the coal.

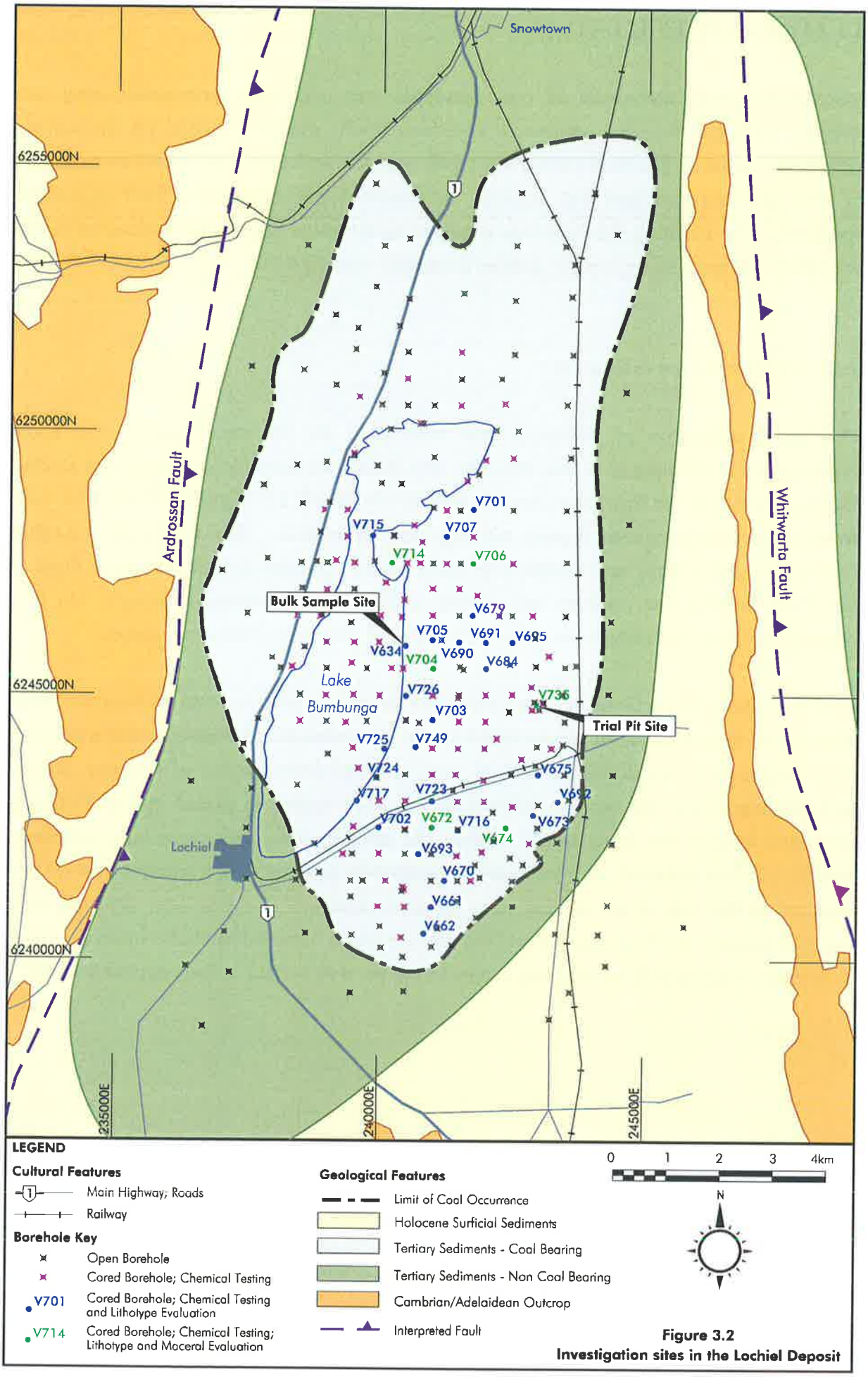



**Figure 3.2**
**Investigation sites in the Lochiel Deposit**

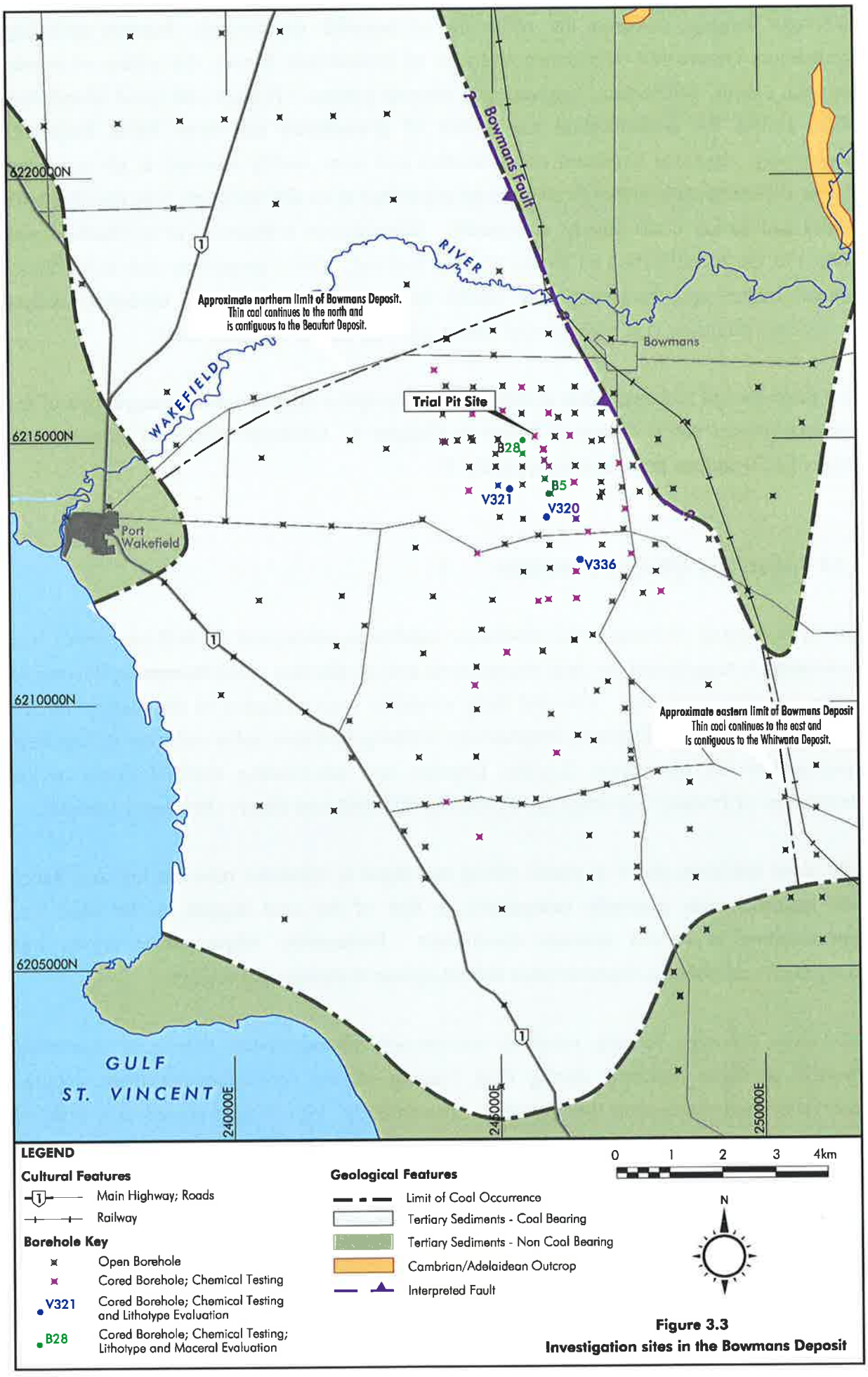



**Figure 3.3**
**Investigation sites in the Bowmans Deposit**

Lithotype logging involved the recording of assorted macroscopic features including groundmass texture (i.e. abundance and size of groundmass tissue), the nature of woody material, colour, gelification, hardness and mineral content. Texture and wood abundance, which reflect the concentration and nature of groundmass and large tissue fragments respectively, represent dominant characteristics and were readily assessed in all instances. Colour differentiation, although suppressed somewhat at in situ moisture, was possible with lighter and darker coals clearly discernable. Macroscopic assessment of gelification was limited to the identification of highly gelified material. Other properties such as hardness, mineral matter and fracturing were useful in specific situations and tended to reflect anomalous conditions (i.e. high mineral matter content, highly fractured coal).

The development and evaluation of appropriate descriptive criteria was an integral part of the research project and is discussed further in Chapter 5. Lithotype logs were prepared at a scale of 1:50 and are presented in Appendix B.

### 3.2.2 Laboratory lithotype evaluation

Lithotype logging of cores under laboratory conditions subsequent to field operations was undertaken to supplement the field observations and, in the case of the Bowmans Deposit, to improve regional coverage. Five and three boreholes were evaluated in this manner for the Lochiel and Bowmans Deposits, respectively, utilising half-core splits collected during field investigations by the author (Lochiel Deposit) and pre-existing material stored at the Department of Primary Industries and Resources (PIRSA) core library (Bowmans Deposit).

Split cores had been stored in plastic tubing and taped to minimise moisture loss and hence their condition was generally comparable to that of the core logged in the field (i.e. approximating to *in situ* moisture conditions). Fortunately, where partial drying was recognised, macroscopic characteristics did not appear to change appreciably.

Laboratory lithotype logging recorded macroscopic characteristics that were essentially identical to those observed during field logging of the core, although more detailed observation and assessment was possible. Accordingly, logs were prepared at a scale of 1:12.5. Laboratory generated lithotype logs are identified in Table 3.2 and presented in Appendix B.

## 3.3 SAMPLING

### 3.3.1 Sample selection

Samples for petrographic, chemical and biomarker evaluation were primarily collected from selected boreholes following field or laboratory lithotype logging, leading to a regularly spaced pattern of detailed investigation sites (Table 3.3, Appendix A). Additional samples were taken wherever logging identified unusual or distinctive coals. Spot and continuous channel samples were also collected during a vertical sidewall traverse of the Lochiel trial pit.

Samples were taken throughout coal seams at a vertical spacing of approximately 0.5 m. Specific sample positions were defined to ensure representative lithotype intervals were obtained and separation was reduced where significant changes occurred. Individual samples were typically 50 to 100 mm thick.

### 3.3.2 Pre-treatment

All coal samples were initially subject to a common test regime involving photography, lithotype assessment, crushing, air-drying and moisture determination. The intact sample was initially photographed under *in situ* moisture conditions together with sample identifiers and standard measures at an approximate scale of 1:2 (i.e. negative to sample). Photographs were compiled as a record of macropetrographic features; and examples demonstrating lithotype attributes and coal criteria are presented in Chapters 5 and 6.

Lithotype evaluation followed photography and likewise was undertaken at *in situ* moisture conditions. Standard lithotype criteria were applied. Primary crushing involved manual reduction of particle size until fragments were reduced to -12.5 mm. A total moisture determination was undertaken at this stage in accordance with Australian Standard AS 2434.1 (1981). Samples were then split into four fractions and utilised for micropetrographic assessment (Section 3.4), biomarker evaluation (Section 3.5) and chemical analysis (Section 3.6). The remaining sample fraction was retained as back up material.

## 3.4 MACERAL ANALYSIS

Maceral assessment involved both point counting and qualitative sample description. The former provided quantitative maceral data for coal classification and palaeoenvironmental assessment, while the latter was used to provide an overview of characteristics and assist coal differentiation and correlation. A total of 78 Lochiel and 87 Bowmans samples were subject

to point counting, with approximately 150 additional samples qualitatively described (Tables 3.3 and 3.4). Maceral data from point counting are presented in Appendix C.

Table 3.4: Point count data summary

| Deposit | Hole | Sample Identification |
|---|---|---|
| Lochiel | V672 | L500, L513 |
| | V674 | L534, L535 |
| | V690 | L154, L156 |
| | V695 | L376 |
| | V704 | 1, 2, 3, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45 |
| | V706 | L540, L541, L542, L543, L544, L545, L546, L547, L548 |
| | V714 | 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74 |
| | S12 | 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114 |
| Bowmans | B5 | 69.9, 70.5, 71.0, 71.1, 72.1, 72.7, 73.5, 73.9, 74.3, 74.9, 75.4, 75.9, 76.4, 76.9, 77.6, 78.1, 78.85, 81.5, 81.95, 82.5, 83.55, 83.95, 84.0, 84.5, 84.95, 85.5, 85.95, 86.5, 86.95, 88.0, 88.5, 89.0, 90.0, 91.0 |
| | B28 | 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, L610, 14, L611, 16, 17, 18, L612, 20, 22, 23, 24, 25, 26, 27, 28, L613, 30, L614, 32, 34, L615, 36, 37, 38, 39, 40, L616, 42, 43, L617, 45, 46, 47, 48, L618, 50, 53, 54, 56, 57, 59, 60, 61 |

### 3.4.1 Sample preparation

The preparation of samples for microscopic assessment involved crushing, mounting in resin blocks and polishing. Procedures were adapted to account for the low rank of the Lochiel and Bowmans coals and closely follow the methodology developed by the former State Electricity Commission of Victoria (SECV) at the Herman Research Laboratory.

A sub-sample was split and crushed to particles less than 2 mm in diameter, from which the -0.0889 mm fraction was separated and retained. Coal grains (minus the fine fraction) were placed in a cold-setting polyester resin, formed into a block mount, cured and sectioned perpendicular to the gravity layering. Grinding and polishing was undertaken over several stages to prepare a sample for microscopic examination, using silicon carbide papers, Magomet alumina powder and 0.25 µm diamond paste, respectively. Wetting agents included kerosene and demineralised water.

### 3.4.2 Point counting

A Leitz Ortholux II microscope equipped with white reflected and fluorescence light modes was used for maceral assessment. The reflected light optical system involved a 12V/100W tungsten halogen light source, light controlling filters (neutral diffusion filter and CB12 filter) and Berek prism. The fluorescence system included a high pressure mercury arc lamp (100 W), heat suppression and excitation filters BG38 and two BG12's, respectively, dichroic

mirror and a barrier filter K510. Oil immersion objectives of x32 and x50, and an eyepiece magnification of x10 to x12.5, were used. The eyepiece was equipped with a graduated cross hair.

Grain mounts were set onto a glass slide using modelling clay and a levelling press. Immersion oil conforming to DIN 58884 (low fluorescing and of refractive index 1.518 at 23 degrees C) was added to the grain mount prior to examination. A 13-parameter mechanical point counting machine and associated point counting stage were used for quantitative assessment. Photographs were taken with a Wild Photoautomat MPS spot camera and used to document assorted maceral features and representative maceral assemblages in both plain reflected light and fluorescence modes. Photographs were retained as a micropetrographic file and examples demonstrating maceral identification criteria and coal characteristics are presented in Chapters 5 and 6.

Each grain mount was examined under both plain reflected and fluorescence light and between 300 and 600 maceral points were counted. Traverses were oriented parallel to the direction of grain settling, with 0.3 mm advances between points. Adjacent traverses were spaced approximately 0.6 mm apart. Maceral identification was undertaken in line with the maceral system described in AS 2856-1986 and subsequently updated to conform to AS 2856.2-1998. In addition, some locally defined sub-macerals were identified and counted where distinctive morphology and microtexture could be consistently recognised (see Section 5.3.6, Appendix C1). Maceral point count data are presented in Appendix C2.

### 3.4.3 Maceral indices

To assist coal discrimination and succinctly summarise micropetrographic data, a number of maceral indices were developed. These are based on concepts applied previously for coalfield studies, with modification where necessary to account for the rank and specific characteristics of the northern St. Vincent Basin coals.

Key maceral indices and the properties they describe are summarised in Table 3.5. Their derivation and application are discussed in Chapters 5, and the results presented in Appendix C2.

Table 3.5 Maceral indices

| Index | Properties Under Evaluation |
|---|---|
| Vitrinite Preservation Index | Relative amount of cellular tissue compared to fragmented components within the vitrinite fraction |
| Liptinite Preservation Index | Relative amount of cellular tissue compared to fragmented components within the liptinite fraction |
| Massive Tissue Index | Relative amount of tissue occurring as woody fragments compared to groundmass tissue |
| Gelification Index | Level of biochemical gelification |
| Liptinite Environmental Index | Nature of the primary liptinite assemblage, with respect to likely source setting |
| Liptinite Alteration Index | Abundance of secondary liptinites, relative to primary liptinites |

## 3.5 BIOMARKER EVALUATION

Samples used for biomarker assessment were selected from the micropetrographic evaluation suite and included representative members of each coal type. In total, 27 samples were evaluated, including 16 from Lochiel and 11 from Bowmans. Gas chromatography-mass spectrometry (GC-MS) was the principal technique used for biomarker identification. The sample set is identified in Table 3.6 and their biomarker data presented in Appendix E.

### 3.5.1 Solvent extraction and liquid chromatography

Samples were crushed to a fine powder in a Siebtechnik mill. Approximately 30 g of powdered coal was transferred to a pre-extracted thimble for Soxhlet extraction, using a mixture of dichloromethane (DCM) and methanol in the ratio of 93:7. A small portion of silica anti-bumping granules and activated copper turnings were also added to the solvent flask. After approximately 72 hours the flask containing the extractable organic matter in solution was transferred to a rotary evaporator for removal of the bulk of the solvent under water-pump vacuum. Upon pipetting the solution into a pre-weighed glass vial, the remainder of the solvent was evaporated on a heating block (40°C) under a capillary stream of dry nitrogen.

A weighed portion of extractable organic matter (EOM: approximately 0.1 g) was dissolved in DCM and mixed with activated silica for column chromatography. This material was added to a packed column of activated silica in petroleum ether. The column was eluted with 80 ml aliquots of petroleum ether, petroleum ether:DCM (50:50) and petroleum ether:methanol (35:65) to retrieve the aliphatic hydrocarbon, aromatic hydrocarbon and polar fractions, respectively. Solvent was removed from these fractions as for the EOM. After weighing the aliphatics were re-dissolved in *n*-hexane prior to GC-MS evaluation.

### 3.5.2 Gas chromatography – mass spectrometry (GC-MS)

GC-MS analysis of the aliphatic hydrocarbons was undertaken using a Varian 3400 gas chromatograph interfaced to a Finnigan TSQ 70 mass spectrometer. The gas chromatograph was fitted with either a 30 m or 60 m x 0.25 mm (internal diameter) fused silica column (DB-1, 0.25μm film thickness). The shorter column was used only in the initial stages of the analytical program and all remaining samples were evaluated using the longer column (Table 3.6). Helium was used as the carrier gas at an inlet pressure of approximately 23.5 psi.

Table 3.6 GC-MS evaluation summary

| Sample Location and Identification | | | | GC-MS Assessment | | |
|---|---|---|---|---|---|---|
| Deposit | Hole | Depth | Name | Geochemical Sample ID | Column Length | Injection Method |
| Lochiel | V704 | 63.15 | 31 | GMS-22 | 60 | SP |
| Lochiel | V704 | 69.35 | 42 | GS-9/GMS-39 | 30/60 | OC/SP |
| Lochiel | V714 | 55.25 | 50 | GMS-20S | 60 | SP |
| Lochiel | V714 | 55.75 | 51 | GS-4A | 30 | SP |
| Lochiel | V714 | 57.55 | 54 | GS-10 | 30 | OC |
| Lochiel | V714 | 58.45 | 56 | GS-56 | 30 | SP |
| Lochiel | V714 | 60.55 | 60 | GS-8/GMS-40;2 | 30/60 | OC/SP |
| Lochiel | V714 | 62.05 | 63 | GS12/GMS-40;1 | 30/60 | OC/SP |
| Lochiel | V714 | 63.55 | 66 | GS-7 | 30 | OC |
| Lochiel | V714 | 67.25 | 69 | GMS-25 | 60 | SP |
| Lochiel | V714 | 68.75 | 72 | GS-11 | 30 | OC |
| Lochiel | V690 | 45.20 | L155 | GMS-21 | 60 | SP |
| Lochiel | V723 | 36.60 | L388 | GS-6 GMS-34 | 30/60 | OC/SP |
| Lochiel | V672 | 37.00 | L502 | GMS-32 | 60 | SP |
| Lochiel | V674 | 32.75 | L535 | GS5/GMS-35 | 30/60 | OC/SP |
| Lochiel | V706 | 55.65 | L543 | GS-1A/GMS-37 | 30/60 | SP |
| Bowmans | B 28 | 63.80 | 4 | GMS-23 | 60 | SP |
| Bowmans | B 28 | 64.30 | 6 | GS-3 | 30 | OC |
| Bowmans | B 28 | 67.00 | L610 | GMS-36 | 60 | SP |
| Bowmans | B 28 | 70.10 | L612 | GMS-33 | 60 | SP |
| Bowmans | B 28 | 71.40 | 23 | GMS-24 | 60 | SP |
| Bowmans | B28 | 74.50 | L613 | GMS-26R | 60 | SP |
| Bowmans | B 28 | 80.50 | L616 | GMS-29 | 60 | SP |
| Bowmans | B 28 | 84.40 | L618 | GMS-28 | 60 | SP |
| Bowmans | B 28 | 86.10 | 54 | GMS-27/GMS-38 | 60 | SP |
| Bowmans | B 28 | 90.30 | 57 | GMS-31 | 60 | SP |
| Bowmans | B 28 | 92.70 | 60 | GMS-30 | 60 | SP |

Note: GC-MS column length: Two columns were used (30 m and 60 m).
GC-MS injection method: Two methods were used (OC - on column, SP - splitless).
Selected samples were run on both columns /injection methods

Injection methods varied between on column and splitless mode (Table 3.6). For on column injection, the oven program included an initial column temperature of 50°C for two minutes, 50°C to 120°C increasing at 8°C per minute, 120°C to 300°C increasing at 4°C per minute and a 35 minute hold time at 300°C. For splitless injection, an initial column temperature of 50°C for 3 seconds, 50°C to 300°C increasing at 180°C per minute and a 5 minute hold time at 300°C were used. Some replicate analyses were undertaken to confirm repeatability and

assess response for differing column lengths and injection methods. All data were collected in scan mode and stored on cartridge tape.

### 3.5.3 Compound identification

Compound identification involved a number of stages and evolved over the course of the project. Assorted *m/z* and mass spectra printouts were first prepared for all GC-MS runs (Table 3.7).

Table 3.7 Ions monitored for biomarker evaluation

| Compound Class | Time Evaluation Window (min) # | *m/z* Ions Monitored |
|---|---|---|
| Sesquiterpenoids | 15-25/20-30 | 123, 204, 206, 208, RIC |
| Diterpenoids | 25-40/30-45 | 123, 257, 259, RIC |
| Des-A triterpenoids | 32-47/45-60 | 123, 312*, 314*, 326*, 328*, 330, RIC |
| Secohopanoids | 32-47/45-60 | 123, RIC |
| Hopanoids | 45-60/54-78 | 189, 191, RIC |
| Intact terrigenous triterpenoids | 45-60/54-78 | 189, 191, 218, 243, 365, 408, RIC |
| A-Ring contracted triterpenoids | 45-60/54-78 | 351, 365, 381, RIC |
| Steroids | 45-60/54-78 | 257, RIC |
| *n*-alkanes | 5-65/15-85 | 99, RIC |

Key: * Available for only a portion of the GC-MS suite
# The two ranges denote times for the 1993 and 1994 evaluations, respectively
RIC = reconstructed ion chromatogram

Initial assessment involved peak numbering and correlation within the various major biomarker classes (i.e. sesquiterpenoids, diterpenoids, etc.) using elution time and compound characteristics. However, the variability in compound occurrence between samples necessitated extensive utilisation of mass spectra to assist peak correlation. Mass spectra were subsequently routinely obtained on all compound peaks. Together with relative elution time they were used an iterative manner for progressive compound assignment.

The compounds detected are summarised in Appendix D1 and mass spectra of major compounds presented in Appendix D2.

### 3.5.4 Semi quantitative biomarker abundance estimation

A precise measure of absolute abundance was not available for the biomarkers identified during this study. However, a semi-quantitative assessment of relative compound abundance across the sample suite was attempted using extract and aliphatic fraction yields, solvent concentrations, sample injection volume and GC-MS response (A. Chaffee, pers. comm., 2001). From this a Relative Concentration Index (RCI) was developed to normalise variations in the parameters contributing to biomarker response.

A number of independent RCI estimations were made for each biomarker, or biomarker class of interest. In each instance a consistent set of peak measurements from specific *m/z* GC-MS traces was employed, with the ions used for index calculation varying between biomarker groups.

The specific methodology for RIC calculation, its limitations, the biomarker groups and compounds assessed using this approach and resultant outputs are presented in Appendix D3.

## 3.6 CHEMICAL AND PHYSICAL ANALYSIS

### 3.6.1 Testing

Conventional chemical analysis was undertaken on all samples collected for maceral assessment (Table 3.3). Parameters of interest included ash content, total sulphur, ash composition (i.e. oxides within the ash) and quartz. Colour Index was determined on a small suite of representative coal types. The sample set used for chemical and physical testing is shown in Table 3.8 and the results presented in Appendix E.

Table 3.8 Coal chemistry sample summary

| Deposit | Borehole | Sample Identification |
|---|---|---|
| Lochiel | V672 | L365, L367, L369, L500, L501, L502, L503, L505, L506, L507, L508, L509, L510, L511, L512, L513, L514, L515, L516, L516, L517, L518 |
| Lochiel | V674 | L530, L531, L532, L533, L534, L535 |
| Lochiel | V675 | L152, L153 |
| Lochiel | V690 | L154, L155, L156, |
| Lochiel | V694 | L157 |
| Lochiel | V701 | L377, L378 |
| Lochiel | V703 | L380 |
| Lochiel | V704 | 1, 2, 3, 8, 22, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45 |
| Lochiel | V706 | L540, L541, L542, L543, L544, L545, L546, L547, L548 |
| Lochiel | V707 | L385 |
| Lochiel | V714 | 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74 |
| Lochiel | V723 | L388, L389, L390 |
| Lochiel | S12 | 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115 |
| Bowmans | B5 | 69.90, 70.50, 71.00, 71.10, 72.10, 72.70, 73.50, 73.90, 74.30, 74.90, 75.40, 75.90, 76.40, 76.90, 77.60, 78.10, 78.85, 81.50, 81.95, 82.50, 83.55, 83.95, 84.00, 84.50, 84.95, 85.50, 85.95, 86.50, 86.95, 88.00, 88.50, 89.00, 90.00, 91.00 |
| Bowmans | B28 | 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, L610, 14, L611, 16, 17, 18, L612, 20, 22, 23, 24, 25, 26, 27, 28, L613, 30, L614, 32, 34, L615, 36, 37, 38, 39, 40, L616, 42, 43, L617, 45, 46, 47, 48, L618, 50, 53, 54, 56, 57, 59, 60, 61 |

Chemical testing utilised Australian Standard analytical procedures (Table 3.9) and was undertaken in ETSA's Torrens Island Power Station chemical laboratories. In addition, quartz content was determined according to an internal ETSA standard from coal ash.

Table 3.9 Standard procedures used for chemical testing

| Test | Relevant Standard Procedure |
|---|---|
| Total moisture | AS 2434.1 (1981) |
| Proximate analysis (including ash content) | AS 1038.3 (1979) |
| Sulphur | AS 1038.6 (1971) Eschka Method |
| Ash analysis | AS 1038.14.1 (1979) |
| Quartz analysis | Internal ETSA standard |

Colour Index measurements were made by the SECV at the Herman Research Laboratory on a suite of 25 samples spanning the range of coal types represented at Lochiel and Bowmans. Samples were air dried and crushed to -300 μm and analyses performed using a Hunterlab Colour/Difference meter D25-2, calibrated according to the manufacturer's instructions. A suite of 5 Latrobe Valley coals spanning the same lithotype range were also tested for comparative purposes.

### 3.6.2 Quartz and kaolinite estimation

The abundance of the major mineral species, kaolinite and quartz, were estimated from ash compositional analysis based on scanning electron microscopy with energy dispersive x-ray spectrography (SEM/EDS) and x-ray diffraction (XRD) investigations and chemical and mineralogical changes detected during combustion. The methodology and its limitations are elaborated in Appendix E1.

## 3.7 COALFIELD EXPLORATION DATA

### 3.7.1 Borehole records

Drilling records (location, elevation and lithological interpretation) and coal analysis (ash composition, ash content and total sulphur) from earlier coalfield exploration in the region were available for boreholes in the Lochiel and Bowmans Deposits. This information was provided by ETSA in the form of computerised geological databases and involved 299 and 318 boreholes from Lochiel and Bowmans, respectively. Where available, geophysical borehole logs (long and short spaced density, caliper, gamma and neutron) were also inspected.

Specific procedures associated with raw data collection and database establishment are documented in internal ETSA and Department of Mines and Energy reports (Meyer 1976, 1992; Springbett, 1980; ETSA Coal Resources Branch, 1983, 1988a, 1988b; Kremor, 1986; G & S Resources, 1993).

### 3.7.2 Seam correlation and assessment

Seam correlation and assessment focuses on the Bowmans Deposit where suites of north-south and east-west cross sections were constructed at intervals of 500 m. These were used for detailed correlation and evaluation of seam geometry, coal occurrence, the nature of splitting, relationships to adjacent clastic intervals and seam termination. In the Lochiel Deposit, this work had previously been completed as part of a detailed sedimentological study by Kremor (1986, 1992).

### 3.7.3 Computer modelling

Estimated quartz and kaolinite abundance, together with analytically determined total sulphur content from exploration boreholes were used to develop deposit-wide computer models for each seam.

Analytical and borehole survey data, together with estimated quartz and kaolinite abundance was uploaded into a computerised database. Individual samples were weighted using thickness and density to produce seam average values for each borehole/assay parameter combination. The resulting data were grid modelled over each seam using Vulcan geological software. A 25 m grid node spacing and an inverse distance modelling technique were employed. Models were subsequently masked to the limit of data availability for each seam.

## 3.8 CO-OPERATIVE RESEARCH

In addition to the investigations performed by the author during this project a number of cooperative studies were undertaken. These involved complementary research into mineral matter species and occurrence, palaeobotany (including wood and cuticle components) and palynology. In each program testing utilised duplicate samples, or split portions of samples collected for the current project.

Closely spaced samples from four detailed investigation sites, including V704 and V714 at Lochiel and B5 and B28 at Bowmans, were used for investigation of crystalline mineral matter by researchers at the University of South Australia (Table 3.3). Techniques included SEM/EDS and XRD. Procedures and results are presented in Readett and Quast (1987), Manuel and Quast (1990) and Quast and Readett (1991).

Two palaeobotanical investigations were undertaken in conjunction with this research, involving cuticle and fossil wood components. The study of dispersed cuticle utilised samples collected by the author from the Lochiel Trial Pit. Work was undertaken by Andrew

Rowett (Botany Department, University of Adelaide) to evaluate floristic composition. Procedures for processing and analysing the dispersed cuticles are detailed in Rowett (1992). Fossil wood assessment was undertaken on a suite of 19 samples collected by the author from two wood rich facies within the Lochiel Trial Pit. Work was undertaken by James Manuel (Geology Department, University of Adelaide). Wood evaluation and identification involved microscopic examination of thin sections and polished blocks, the results of which are presented in Manuel (1988).

Palynological evaluation was undertaken on samples from three sites in the Lochiel Deposit (boreholes V674, V714 and the trial pit site S12) and two boreholes from the Bowmans Deposit (B5 and B28). In total 26 samples were examined by Liliana Stoian (Department of Primary Industries and Resources, South Australia). The results of this study are presented in Stoian (2003).

# 4 REGIONAL GEOLOGICAL SETTING OF THE BOWMANS AND LOCHIEL COAL DEPOSITS IN THE NORTHERN ST. VINCENT BASIN

This chapter provides a brief review of the geology, stratigraphy and structure of the northern portion of the St. Vincent Basin. Particular attention is paid to the occurrence and gross seam attributes of coal measures within its two most prospective fossil fuel deposits at Bowmans and Lochiel. Finally, a comparative overview of coal accumulation is developed in which the mechanisms responsible for the characteristic features of each deposit are identified.

## 4.1 ST. VINCENT BASIN

The St. Vincent Basin is an intracratonic depocentre located near the present continental margin in southern South Australia (Figure 4.1). It contains up to 700 m of Tertiary terrestrial and marine sediments in a shallow graben, bounded by fault blocks of folded Proterozoic and Palaeozoic rocks (Lindsay and Alley, 1995). A prominent marine gulf and adjacent lowlands probably typified the regional depositional setting throughout much of its history (Cooper, 1985).

The St. Vincent Basin straddles the Torrens Hinge Zone, a transitional structural zone between the Gawler Craton in the west and the Adelaide Geosyncline in the east (Figure 4.1). Basin formation was initiated by down faulting in the Middle Eocene associated with an increased rate of separation of the Australian and Antarctic plates (Cooper, 1985). Reactivation of N-S trending Delamerian structures within the surrounding Proterozoic and Palaeozoic succession and differential mobility between the south east corner of the Gawler Craton and the western margin of the Adelaide Geosyncline resulted in an approximately N-S basin axis (Cooper, 1985; Benbow *et al.*, 1995).

Faulting was probably most active immediately after basin formation, with another distinct period in the early to mid Pleistocene (Cooper, 1985). The absence of a basal conglomeratic facies in the basin fill led Stuart (1969) to suggest that only mild structural movement was required to initiate sedimentation. The southern part of the basin is largely separated from the continental margin by Kangaroo Island which appears to have restricted access to the open ocean through much of its history (Lindsay and Alley, 1995), whereas in the north a narrow corridor provided a connection to the Pirie Basin (Kremor, 1992).

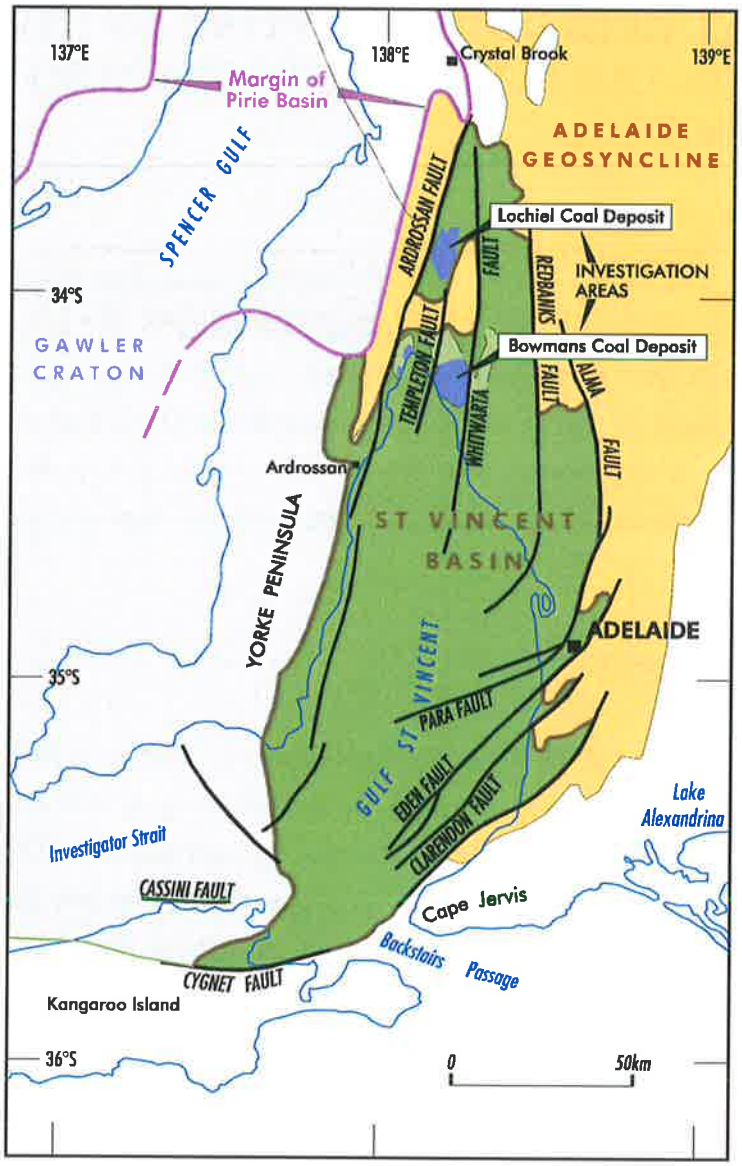



Figure 4.1 Geology of the St. Vincent Basin

Deposition commenced in the Mid-Eocene with extensive flooding of the continental margin (Benbow *et al.*, 1995) and coincided with a period of high rainfall, possibly rapid erosion and active drainage systems over much of the region. Shallow marine sedimentation was common throughout the St. Vincent Basin, although non-marine clastic deposition occurred over significant areas, especially in the early phases of the basin's history (Stuart, 1969; Lindsay and Alley, 1995) and in the north where marine incursions were less frequent (Cooper, 1985). The stratigraphic succession, from non-marine clastics to marine temperate limestones, reflects progressive onlap and northward transgression (Lindsay and Alley, 1995). The principal loci of deposition are the product of localised tectonics, typically occurring on the downthrown sides of major faults (Cooper, 1985). Palaeocurrent data (Stuart, 1969) indicate that sediment transport was directed towards the present basin axis by numerous stream channels and involved rapid downcutting and reworking of previously deposited sediments.

Non seasonal subtropical climatic conditions during the Middle to Late Eocene lead resulted in warm temperate rainforests (see Section 2.4.2) and significant biomass production. Peats accumulated in paralic settings created by major transgressive episodes (Harris, 1985; Holdgate and Clarke, 2000). Kremor (1992) suggested a midplate continental margin setting and peat deposition at highstands of minor regressive episodes within a broad transgressive system tract sequence. According to Holdgate and Clarke (2000), the resulting coals mark the early stages of the transgressive systems tracts.

## 4.2 COAL GEOLOGY OF THE NORTHERN ST. VINCENT BASIN

### 4.2.1 Location and relationships

Coals have been reported from numerous locations in the St. Vincent Basin including the Adelaide region (Lindsay, 1981), although major accumulations are restricted to the northern end of the basin within bedrock depressions, or half grabens (Stuart, 1969; Lindsay, 1981; Harris, 1985; Kremor, 1992; Kremor *et al.*, 1995; Lindsay and Alley, 1995; Figure 4.2). The thickest coal developments commonly occur in close proximity to major faults, while structurally elevated areas appear to have been exposed, representing unsuitable sites for peat accumulation and preservation.

Coal is thickest and most extensive around the top of Gulf St. Vincent. Here a region of approximately 20 km by 25 km (east-west by north-south, respectively) incorporates the Bowmans, Whitwarta and Beaufort Coal Deposits, as well as the nearby and possibly contiguous Clinton Deposit (Figure 4.2). The four deposits lie in areas of local thickening adjacent to fault-bounded structural lows which are thought to have influenced coal distribution (Johnson, 1960; Meyer, 1976). Two additional, discrete occurrences exist further to the north. These include the Lochiel and Snowtown Deposits, with regional extents of approximately 75 $km^2$ and 45 $km^2$, respectively (Figures 4.2 and 4.3). The coal measures in question become younger to the north, ranging in age from the Middle Eocene - Early Oligocene at Bowmans (Harris, 1982; Lindsay and Alley, 1995; Stoian, 2003) to Late Eocene - Early Oligocene at Lochiel (Kremor, 1992; Lindsay and Alley, 1995; Stoian, 2003), continuing a diachronous trend evident further to the south in the St. Vincent Basin (Figure 4.4).

The Bowmans Deposit is the largest (Figure 4.2) with three principal seams attaining a cumulative thickness of approximately 26 m, in a shallow, probably fault-induced basement depression (Figure 4.3). Coal thickness is greatest in the northeast of the deposit, with a

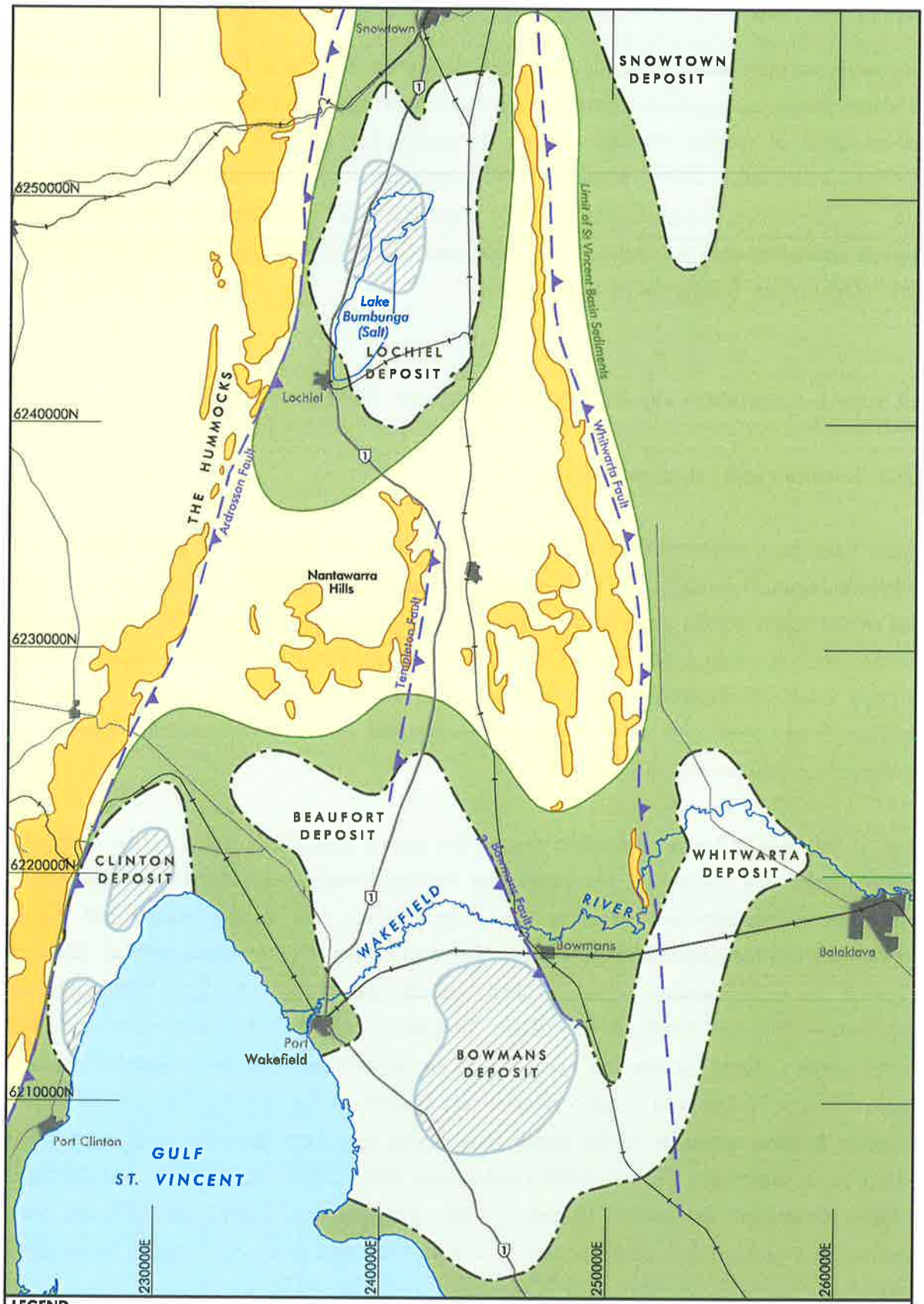



**Figure 4.2**
**Coalfields of the Northern St. Vincent Basin**

gradual reduction to the south and west and rapid thinning to the north and east. The Clinton Deposit lies on the western side of Gulf St. Vincent immediately east of the Ardrossan Fault (Figure 4.2), within a half-graben that contains two main coal seams with a maximum cumulative thickness of 20 m. The eastern limit of coal occurrence is undefined, with the seams extending under Gulf St. Vincent. In the Beaufort area multiple seams from 2 m to 5 m thick occur, attaining a maximum cumulative thickness of approximately 13.5 m within a gentle basement depression. The Whitwarta Deposit contains one major coal zone which reaches a maximum thickness of 9 m.

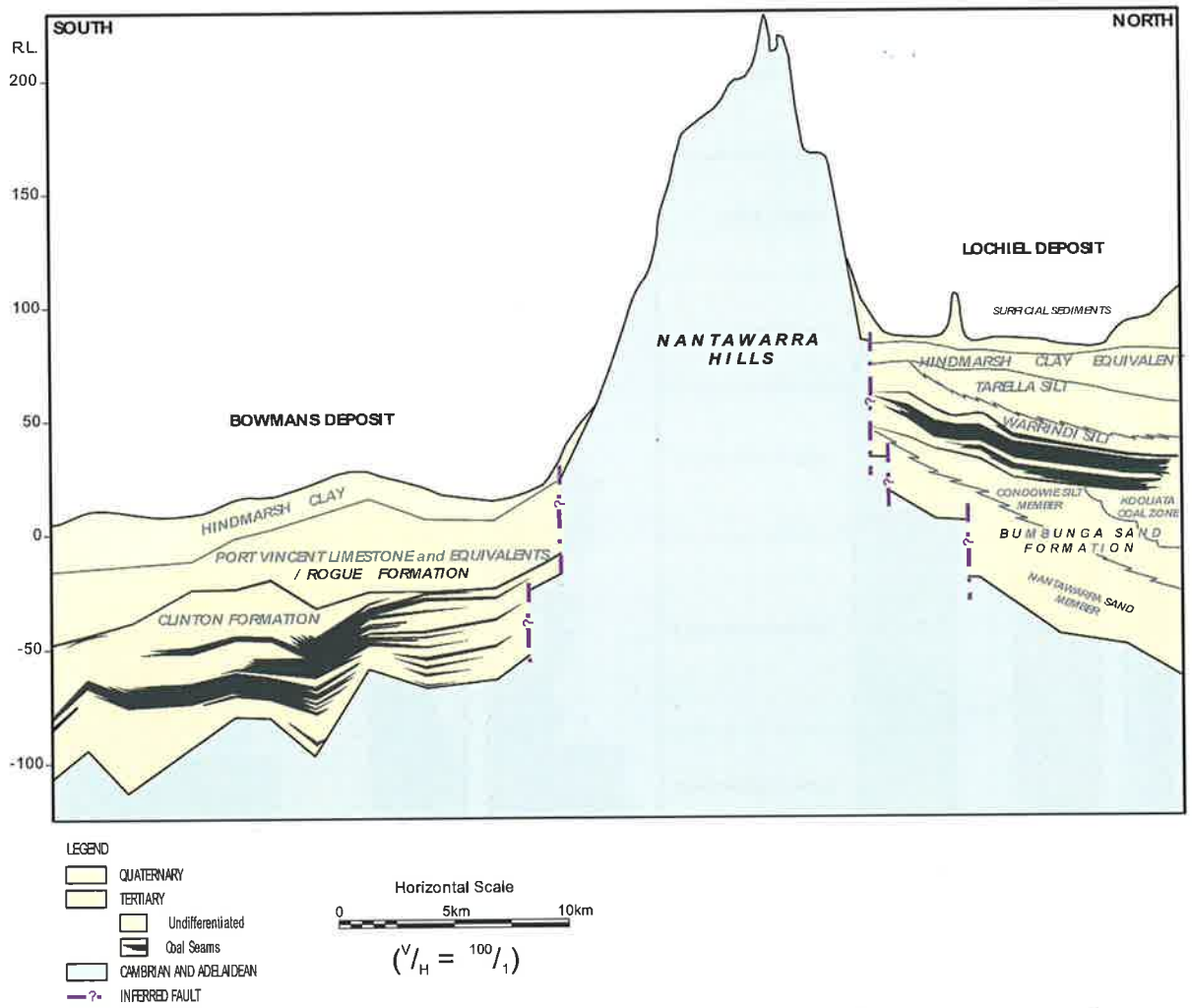
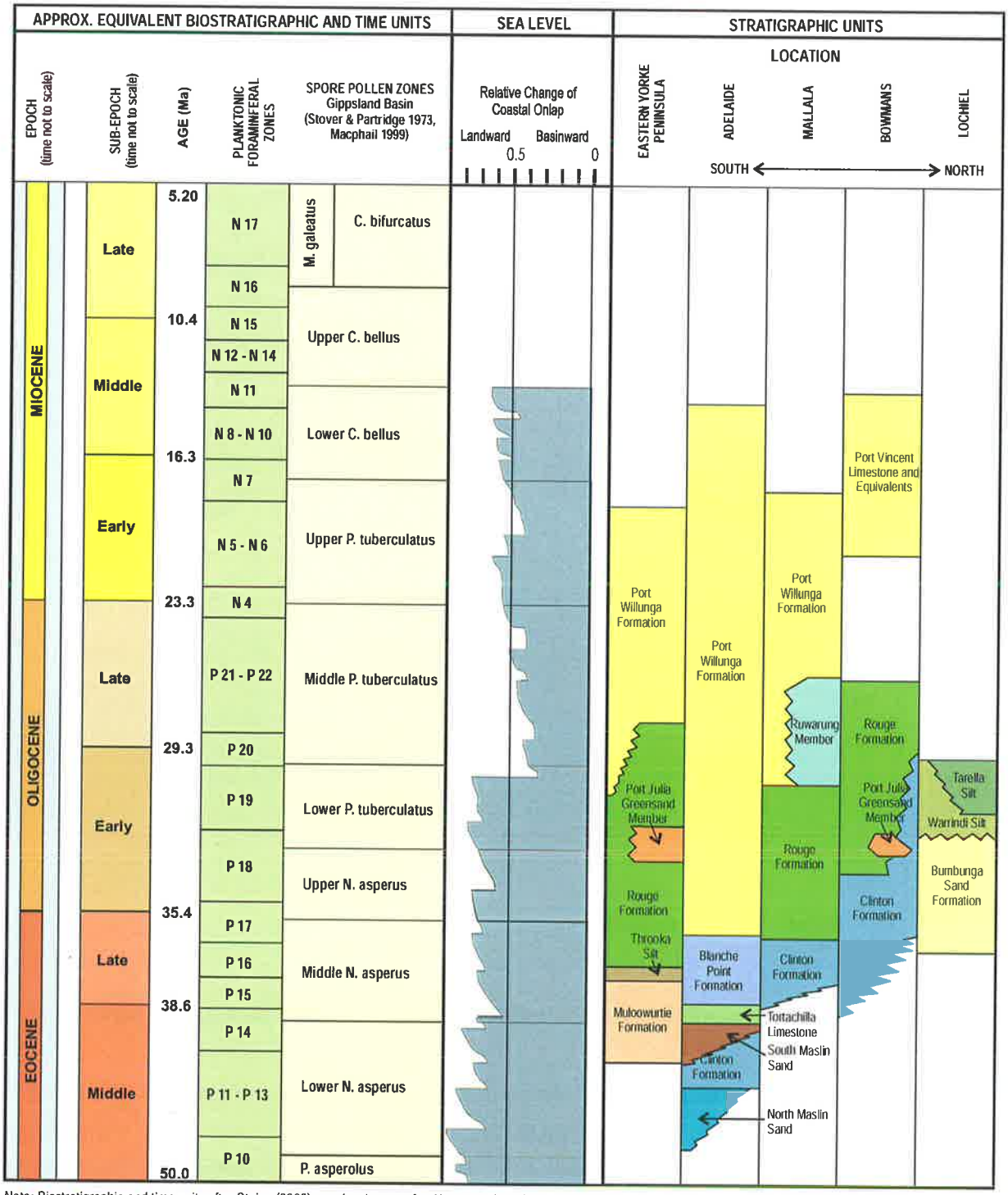



Figure 4.3 North-south cross section through the Lochiel and Bowmans Deposits

In the Lochiel Deposit, three principal seams attaining a maximum cumulative thickness of approximately 15 m occur within a small tectonically controlled sub-basin between the Ardrossan and Whitwarta Faults (Figure 4.2). From palaeocurrent analysis Kremor (1992) interpreted a major western source for the clastic sediments of the Lochiel Sub-basin during the Late Eocene, although the overall drainage direction of the streams was to the north where they possibly coalesced with the ancestral Broughton River, identified by Alley (1973) and Rowett (1997) as the major palaeodrainage system of the region. While the Lochiel depocentre was separated from the Bowmans area by the Nantawarra Hills at the time of peat

accumulation, Kremor (1992) postulated that it was connected to the Pirie Basin in the northwest (Figure 4.1). The Snowtown Deposit occurs in a shallow basement depression east of the Whitwarta Fault and contains two seams with a maximum cumulative thickness of approximately 7 m.




Note: Biostratigraphic and time units after Stoian (2003), sea level curve after Haq *et al.* (1988) and stratigraphic units after Lindsay and Alley (1995), Stoian (2003)

Figure 4.4 Correlation chart for Tertiary strata in the St. Vincent Basin

### 4.2.2 History of coalfield investigations

Interest in fuel supplies stimulated and maintained exploration over northern St. Vincent Basin coalfields for several decades. Investigations commenced in 1922 after coal was reported in water bores and continued until the mid 1980's, progressively extending the known area of coal occurrence. Coal seams are overlain by thick Tertiary and Quaternary sediments and hence their evaluation has relied almost exclusively on drilling.

Early investigations focused around the upper reaches of Gulf St. Vincent and included areas now known as the Bowmans and Clinton Deposits. Initial stratigraphic and structural findings were documented by Johnson (1960) and Hillwood (1961) and the extent of Tertiary sediments defined from surface mapping by Horwitz (1959) and Thompson (1969). The biostratigraphy of the Tertiary succession was first examined by Steel (1961), with subsequent investigations by Harris (1966) and Cooper (1977). More recent palynological investigations were undertaken by Harris (1982), Meakin (1986) and Stoian (1999, 2003), while preliminary petrological studies of the coal were undertaken by Smyth and Harrison (1976) and Smyth (1977). Results from renewed exploration in the 1970's and 1980's are documented in a series of geological and resources evaluation studies, (Meyer, 1976, 1992; Springbett, 1980, 1981; G & S Resources, 1993).

The Lochiel Deposit, discovered in 1982, has been the subject of fewer investigations than have the southern deposits. Its sedimentology and stratigraphy were documented by ETSA's Coal Resources Department (1983, 1988a, 1988b), Kremor (1986, 1992) and Kremor *et. al.* (1995), while palynological investigations were undertaken by Harris (1983) and Stoian (1999, 2003). In other studies, the characteristics of its coals were investigated by G & S Resources (1984, 1988) and ETSA's Coal Resources Department (1988c), its fossil wood was examined by Manuel (1988) and its cuticular remains evaluated by Rowett (1992).

### 4.2.3 Stratigraphy

The Bowmans and Lochiel Deposits are separated by an uplifted block of pre-Tertiary basement (viz. the Nantawarra Hills) and their stratigraphic nomenclature differs (Figure 4.3). However, similar coal-bearing sediments occur in both sequences and constitute the initial terrestrial phase of basin fill (Figures 4.4 and 4.5). In the southern area incorporating Bowmans, the stratigraphic nomenclature is based on a combination of locally defined units (Harris, 1966), and correlations with sediments from the Maslins/Aldinga succession approximately 130 km to the south east (Steel, 1961) and those of the Yorke Peninsula coast approximately 60 km to the south west (Stuart, 1969; Cooper, 1977). The stratigraphy in the Lochiel Sub-basin was defined by Kremor (1986, 1992), from local coalfield investigations.

#### 4.2.3.1 Area south of the Nantawarra Hills

South of the Nantawarra Hills sediments of the St. Vincent Basin bordering the head of Gulf St. Vincent are approximately 120 m thick and rest unconformably on Adelaidean to Cambrian bedrock. Four formations ranging in age from Middle Eocene to Quaternary are represented (Figure 4.5a).

Middle Eocene to Early Oligocene coal-bearing, fluvio-lacustrine sediments of the Clinton Formation form the basal part of the succession (Harris, 1982; Lindsay and Alley, 1995; Stoian, 2003). The sequence was initially termed the Clinton Coal Measures by Harris (1966) and comprises low-rank brown coals (lignites) interbedded with sands, silts and clays, all variably carbonaceous. The formation is time transgressive and becomes younger and shallower to the north, in line with progressive onlap, (Cooper, 1985; Harris, 1985). A short hiatus was recognised by Meakin (1986) and Stoian (2003) and the majority of the formation is though to be Middle - Late Eocene in age (Harris, 1982; Lindsay and Alley, 1995; Stoian, 2003).

Sediments of the Clinton Formation are interpreted as channel, point bar and flood plain deposits, (Stuart, 1969), although in the Bowmans and Clinton area Lindsay and Alley (1995) recognised estuarine to deltaic and fluvio-lacustrine environments. In the Bowmans area the sequence is approximately 70 m thick and is dominated by sands with thick coal beds and occasional silty horizons, especially lower in the sequence. While the sediments are essentially terrestrial, marine dinoflagellates (albeit poorly preserved and in low abundance) have been detected within the coals (Meakin, 1985; Stoian, 2003). Their frequency decreases northward (Meakin, 1985; Harris, 1982), while Stoian (2003) reported an irregular dinoflagellate distribution through the coal sequence with the highest abundance occurring in the uppermost seam.

The Early Oligocene, marginal marine to marine Rogue Formation overlies the Clinton Formation with apparent conformity and thins diachronously towards the northern portion of the basin, ranging from approximately 15 to 35 m (Cooper, 1977). The formation shows considerable lithological variation from south to north, whereby the chert, glauconitic clays, fine sands and minor limestone of the south, including the Point Julia Greensand (Steel, 1961; Cooper, 1977) are replaced by fine to medium grained sands and silty sands near the northern extremity of the Bowmans Deposit. This lateral facies change and northward reduction in glauconitic, calcareous and fossiliferous contents is thought to represent the transition from open marine to marginal marine barrier bar and shoreface settings.

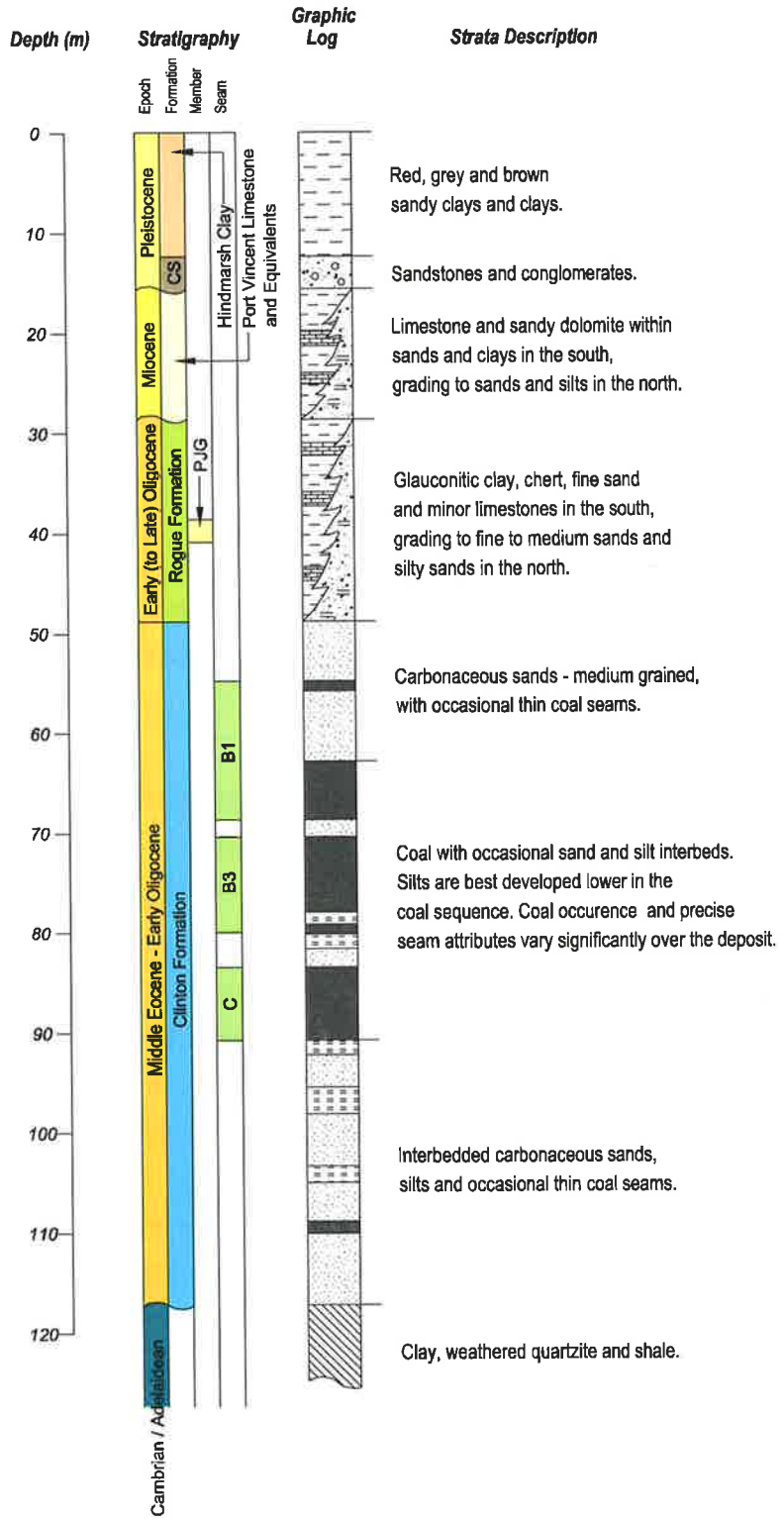



Figure 4.5a Stratigraphy of the Bowmans Deposit

Early to Middle Miocene marginal marine to fully marine sediments of the Port Vincent Limestone and its equivalents complete the Tertiary succession and includes a 15 to 20 m-thick sequence of bryozoal limestone and sandy dolostone interbedded with sands and clays. This formation also thins diachronously towards the northern portion of the basin (Cooper, 1977) and shows a marked facies change whereby limestones are limited to the southern

portion of the Bowmans Deposit (Steel, 1961; Meyer, 1976). The lateral variation is interpreted as the northward transition from open marine to marginal marine conditions, with the condensed nature of the section reflecting multiple transgressive episodes bounded by disconformities (Steel, 1961; Cooper, 1977).

The Quaternary Carisbrooke Sand comprising up to 5 m of poorly sorted sand and conglomerate (Meyer, 1992) and the Hindmarsh Clay consisting of 10 to 20 m of red, grey and brown clays, in part sandy, complete the sequence.

#### 4.2.3.2 Lochiel Sub-basin

In the Lochiel Sub-basin, approximately 100 m of Late Eocene to Early Oligocene sediments were deposited on Adelaidean to Cambrian bedrock. Three major formations are recognised (Kremor, 1986, 1992; Figure 4.5b).

The fluvio-lacustrine Bumbunga Sand Formation constitutes the initial phase of Tertiary sedimentation and ranges from Late Eocene to Early Oligocene in age (Harris, 1982, 1983; Rowett, 1992; Stoian, 2003). It has been subdivided into the Nantawarra Sand, Condowie Silt and Kooliata Coal Members (Kremor, 1992). The basal Nantawarra Sand Member consists mostly of medium sand with silty and coaly beds, with decreasing sand thickness and grain size to the south. From this Kremor (1986, 1992) interpreted a transition from a northern braided stream fluvial belt, to a distributary system and ultimately peat swamps and lakes in the south. Sandy carbonaceous silts and sands comprise the Condowie Silt Member, showing lateral coarsening to margins and thickening towards the centre. The member was considered to represent predominantly lacustrine sedimentation, except for sandy shoreline conditions and marginal forest swamp facies in the south (Kremor, 1986, 1992). Significant coal development is limited to the Kooliata Coal Member, where three seams occur over an interval of approximately 20 m. The coals are separated by silt, sand and silty carbonaceous sands deposited in peat swamp and fluviatile/delta fan environments, respectively (Kremor, 1992). While the sequence is terrestrial in nature, rare marine dinoflagellates have been detected within and immediately below the Lochiel coals (Rowett and Stoian, 1999; Stoian, 2003).

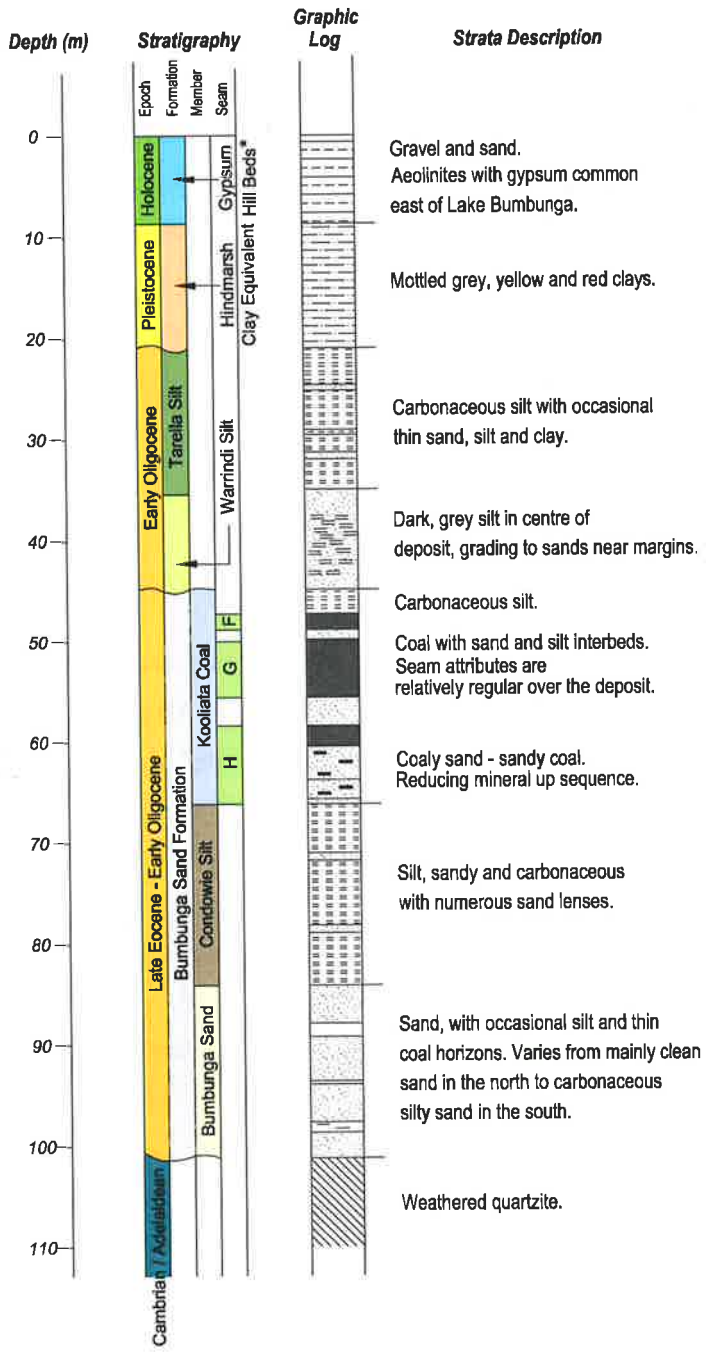



Figure 4.5b Stratigraphy of the Lochiel Deposit

A period of gentle uplift and weathering followed the deposition of coal-bearing sediments, and preceded accumulation of the Early Oligocene, marginal marine Warrindi Silt and Tarella Silt. The former comprises up to 13 m of silty clastics that coarsen toward the basin margins and onlap basement to the south and east, while the latter includes up to 25 m of carbonaceous silt which becomes finer and more carbonaceous up sequence. Kremor (1986, 1992) inferred coeval deposition within laterally contiguous marginal marine barrier bar or lagoonal and estuarine settings for the sediments of the Warrindi and Tarella Silts, respectively, with the landward edge preserved in the Lochiel area. The lateral disposition of these units indicates that the estuarine complex was migrating to the south.

Quaternary sediments consisting of the Pleistocene Hindmarsh Clay Equivalent and assorted surficial deposits overlie the Tertiary succession. The former contains 5 - 20 m of sandy clays, while the latter, including the Maro Creek Sand (sandy clays), Gypsum Hill Beds (gypsiferous silty clays) and Tarama Beds (interbedded cobble and gravel beds with clay), range in thickness from less than 5 m to greater than 85 m. These surficial deposits are associated with the outbuilding of alluvial fans from the Bumbunga Range in the west and a lunette on the eastern side of Lake Bumbunga. A thin veneer of evaporitic sediments also occurs in the Lake Bumbunga region.

### 4.2.4 Structure

The St. Vincent Basin is bounded by approximately north-south trending, and northward converging faults (Figure 4.1). In the northern part of the basin these include the Ardrossan Fault, located immediately west of the Clinton and Lochiel Deposits and displacing Tertiary sediments by approximately 500 m (Kremor, 1992), and the Redbanks Fault in the east. In addition, centrally located faults, such as the Templeton and Whitwarta Faults parallel the dominant north-south orientation. Faults trending southeast were also postulated by Johnson (1960), while some additional structures trending approximately east-west were interpreted by Kremor (1986, 1992). The interaction of these structures results in an uplifted zone of Cambrian and Adelaidean bedrock know as the Nantawarra Hills, isolating the Lochiel Deposit from the more laterally extensive southern deposits, including Bowmans (Figure 4.2).

The first detailed structural interpretation of the region south of the Nantawarra Hills was prepared by Johnson (1960), who suggested three structural zones. These are the central Port Wakefield Platform, where the basement surface although undulating is relatively level; the Whitwarta Sub-basin to the east; and the Clinton Trough to the west. North of the Bowmans and Beaufort Deposits, approximately east-trending faults, downthrown to the south were proposed on the southern margin of the Nantawarra Hills. However, Johnson (1960) noted that differences in basement levels were not extreme and could also result from mild warping of the pre-Tertiary land surface, with some relief due to differential erosion. The interaction of inferred east-trending structures with the Whitwarta Fault is thought to have created a hinge zone, about which the magnitude and sense of movement varied from downthrown in the east (north of the hinge zone) to downthrown in the west (south of the hinge zone: Johnson, 1960; Meyer, 1976; Kremor, 1992). Later investigations of the Bowmans area (Springbett, 1980; Meyer, 1992), although not substantially modifying the aforementioned structural interpretation, have identified an abrupt change in basement elevation near the Bowmans railway siding, and an approximately north-trending fault downthrown to the west, with diminishing throw to the south, termed the Bowmans Fault is inferred (Figure 4.2).

North of the Nantawarra Hills the Lochiel Deposit occupies a small sub-basin between the Ardrossan and Whitwarta Faults. Both faults are down thrown to the east and together form a half graben in which the sediments dip gently to the west at approximately 1°. Kremor (1986, 1992) recognised a number of structures approximately parallel and orthogonal to the basin bounding faults, although faulting of Tertiary sediments appears limited to the Ardrossan Fault. Elsewhere, basement faults acted as hinge zones about which very gentle monoclinal folding occurred (Kremor, 1992).

### 4.2.5 Coal rank and classification

Various physical, maceral, chemical and biomarker properties of coals can be used to assess their rank, although not all are suitable over the full maturity range (Stach *et al.*, 1982). Parameters commonly used in rank evaluation and coal classification are summarised in Table 4.1, along with their typical values for the brown coals at Bowmans and Lochiel.

Table 4.1 Rank assessment and classification parameters

| Parameter | Bowmans Deposit | Lochiel Deposit |
|---|---|---|
| Total moisture content (% in situ) * | 55.5 | 61 |
| Vitrinite reflectance ($R_{V\ max}$) | 0.25 # | na |
| Carbon (% dmif) | 65.5 | 65.1 |
| Oxygen (% dmif) | 24.5 | 26.3 |
| Hydrogen (% dmif) | 4.9 | 4.9 |
| Volatile matter (% dmif) | 53.6 | 54.7 |
| Gross specific energy (MJ/kg maf) | 12.5 | 10.8 |
| Gross specific energy (MJ/kg daf) | 28.1 | 27.7 |
| CPI | 8.1 | 9.1 |

Key: * Sensitive in the low rank range (Stach *et al.*, 1982)
dmif = dry mineral and inorganic free (based on project sample set)
maf = *in situ* moisture, ash free
# $R_{V\ max}$ determination is from Smyth and Harrison (1976)
na = not available

According to the Australian coal classification (AS 2096-1987) the Bowmans and Lochiel coals are defined as low rank (i.e. their gross specific energy is less than 21 MJ/kg on a maf basis); and with respect to traditional systems they are classified as brown coal (i.e. gross specific energy less than 19 MJ/kg maf). These rankings indicate only minor coalification has occurred within the St. Vincent Basin deposits. However, a slight difference is evident between deposits with coals from the Bowmans Deposit consistently showing higher thermal maturity.

The brown coal definition of the Australian standard encompasses the lignitic classes defined in the American (ASTM) coal classification and regards the terms lignite and brown coal as

synonymous. The term soft brown coal, used in European classifications to indicate high-moisture coals with a very low level of coalification (i.e. next stage after peat), is also a suitable term to describe the Lochiel and Bowmans coals. However, the general term brown coal is applied for consistency throughout the remainder of this thesis.

## 4.3 THE BOWMANS COAL DEPOSIT

### 4.3.1 Seam occurrence and characteristics

In the Bowmans Deposit coal occurs in three principal seams (termed C, B3 and B1 in ascending stratigraphic order) and a number of thin, locally developed horizons (Figure 4.6). The areal extents of individual seams decrease markedly up section as they contract to the north of the deposit. The deposit is characterised by extensive splitting and thinning of seams away from their depocentres, particularly in the B3 and B1 Seams. Maximum seam thickness is typically of the order of 10 m.

#### 4.3.1.1 Unnamed basal seams

The oldest coal accumulations are thin seams (0.5 - 2 m) within the basal portion of the Clinton Formation. In some instances they immediately overlie clays weathered from pre-Tertiary bedrock, but can occur at several stratigraphic levels throughout a 25 m-thick sequence of sands and silts. In terms of thickness and lateral continuity, these coals are best developed within shallow bedrock depressions, where seams can be correlated over intervals of approximately 3 km. However, more typically they form discontinuous, local features.

#### 4.3.1.2 C Seam

C Seam is the most extensive and consistent of the three principal Bowmans seams and occurs over an area exceeding 150 $km^2$ (Figures 4.7 and 4.8). The seam is generally represented by a single coal horizon, typically between 6 and 8 m thick, with only gradual variations evident over most of the deposit. Two zones of localised thickening to >10 m occur in the northeast and southwest.

Significant splitting is evident along the northeastern margin of the deposit, where seams terminate in the immediate vicinity of a pre-Tertiary bedrock high. Elsewhere moderate splitting occurs in the west, and the coal thins gradually to the south. Thin, discontinuous

silty interbeds (up to 0.5 m) are widespread, although irregular, throughout the lower half of the seam.

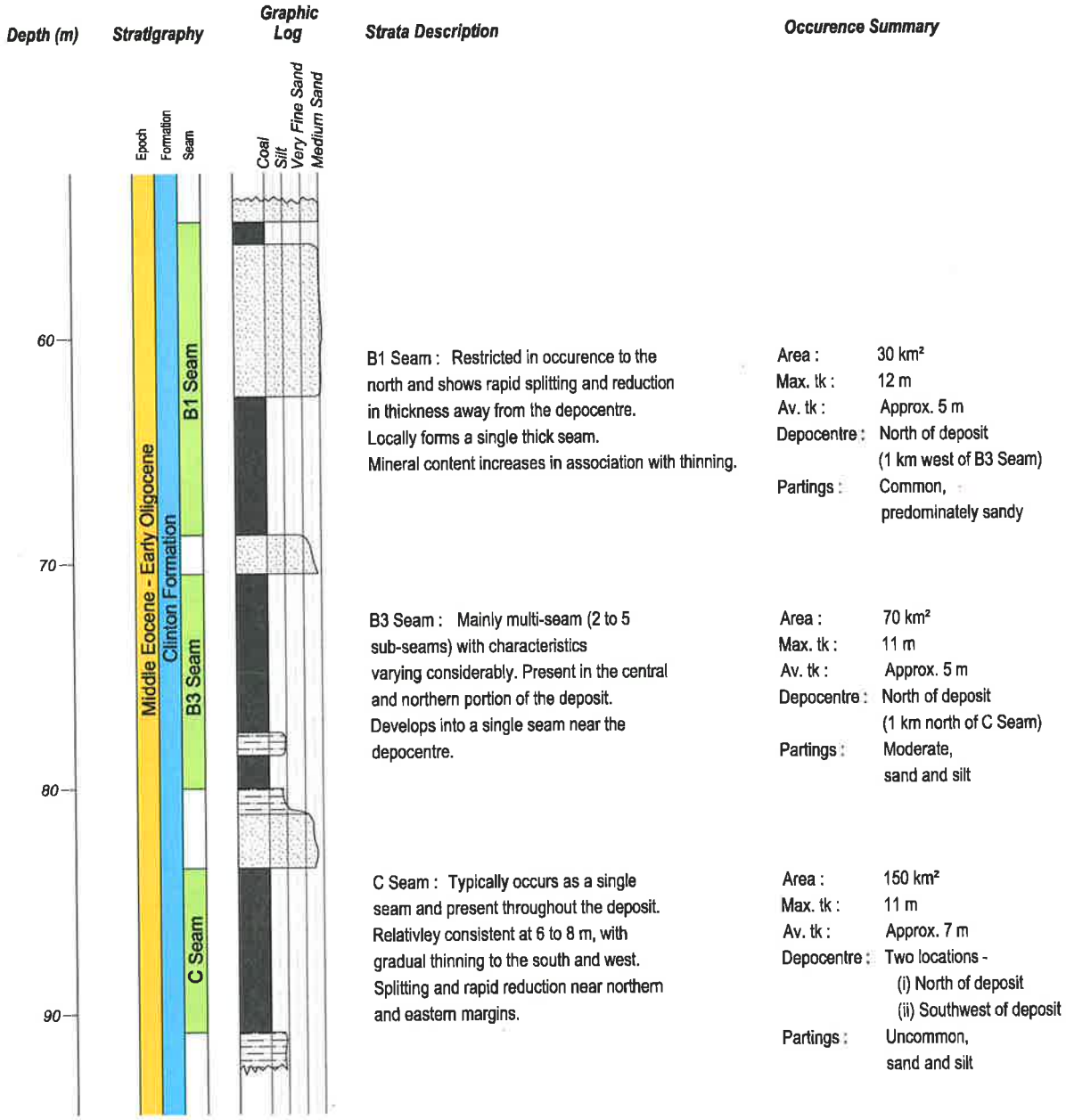



Figure 4.6 Coal stratigraphy of the Bowmans Deposit

### 4.3.1.3 B3 Seam

The B3 Seam is separated from C Seam by 1- 2 m of silt and fine sand. It is restricted to the central and northern portions of the deposit where it covers an area of approximately 70 km$^2$ (Figures 4.7 and 4.8). A maximum seam thickness of 11 m is attained in a well defined depocentre in the northeast of the deposit, immediately west of shallow pre-Tertiary bedrock. Relative to C Seam, the depocentre has migrated approximately 1 km northward.

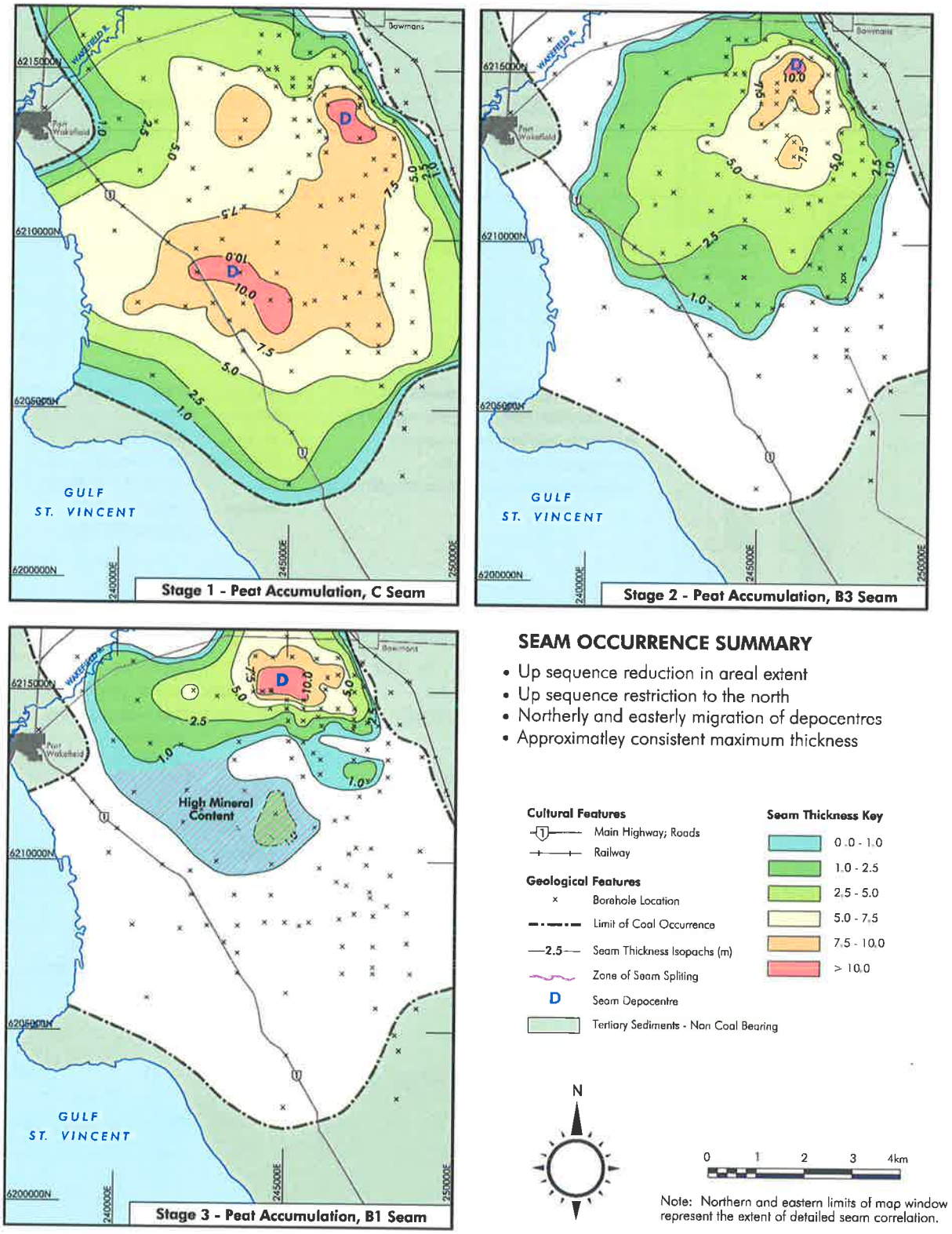



Figure 4.7 Seam occurrence and characteristics in the Bowmans Deposit

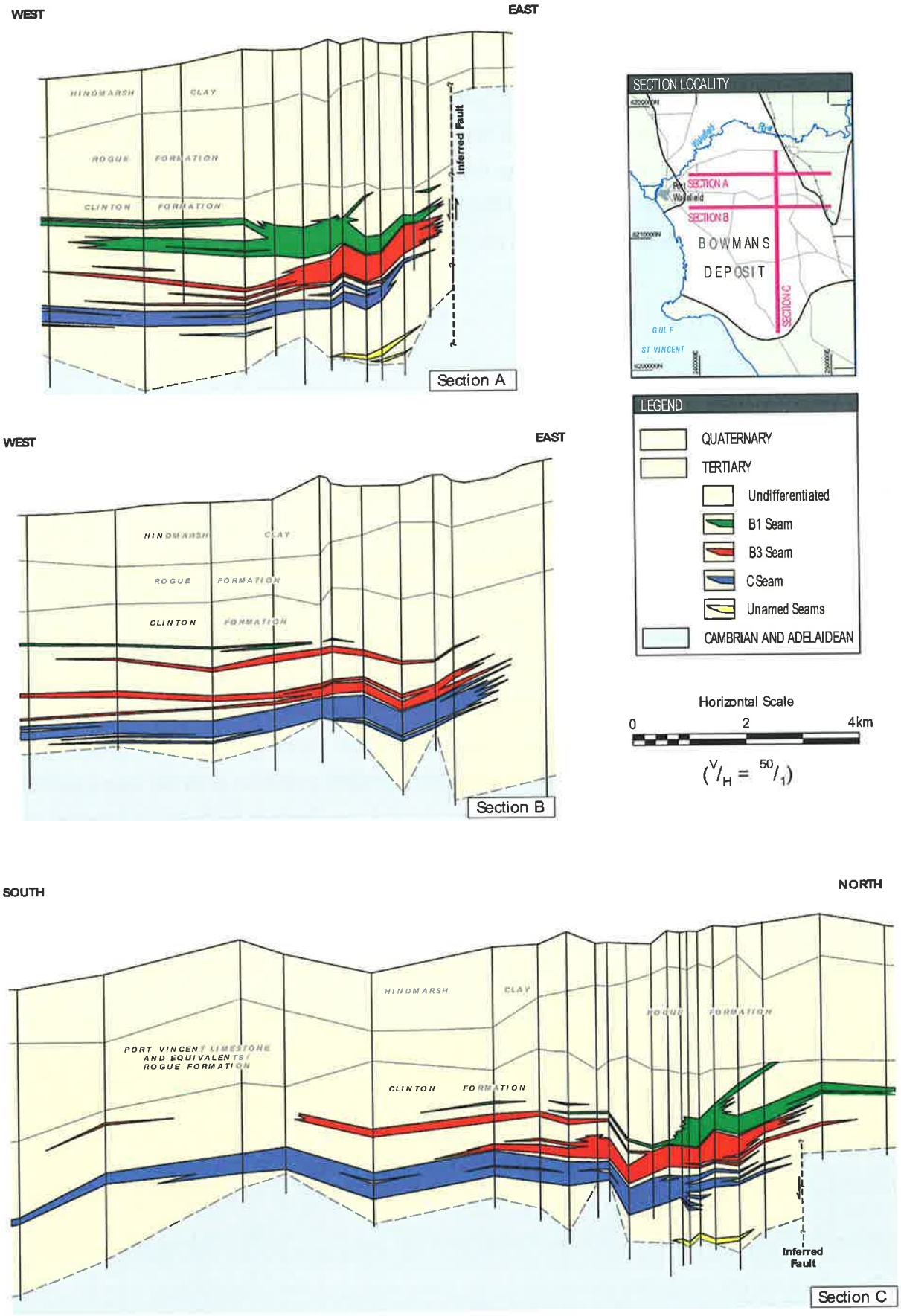



Figure 4.8 Representative cross sections through the Bowmans Deposit

Seam characteristics change considerably in line with splitting. From a single, continuous coal horizon near the seam depocentre, the seam splits into as many as five sub-seams separated by clastic sediments in the south and west. Rapid splitting and thinning occurs toward shallow bedrock in the north and east leading to seam termination. The most widely encountered seam architecture comprises two closely spaced basal sub-seams separated by silt, a sandy interval 5-10 m thick, and a thin upper sub-seam. In contrast to the C Seam, partial onlap and progradation on to the pre-Tertiary bedrock high occurs in the northeast.

#### 4.3.1.4 B1 Seam

The uppermost major coal horizon (i.e. B1 Seam) is restricted to an area of approximately 30 $km^2$ in the northern portion of the deposit and displays the greatest variability. It is typically separated from the B3 Seam by 1-5 m of carbonaceous sand, although the two seams locally coalesce. The depocentre occupies a northerly position and is offset towards the west by approximately 1 km relative to that of the underlying B3 Seam (Figures 4.7 and 4.8).

This seam's characteristics are highly variable. Near the depocentre it is a single seam approximately 12 m thick, from where it thins rapidly in all directions. The most pronounced changes occur along a north-south axis, where the seam splits and thins to approximately 2 m over a distance of 500 m (Figure 4.9). To the south of this zone, up to two thin, sand rich sub-seams (grading laterally into coaly sand) exist and possibly correlate with the basal portion of the seam. In the east, rapid splitting, thinning toward pre Tertiary bedrock and partial onlap occurs, while to the north and west splitting and more gradual thinning are evident. The most substantial and persistent of the sub-seams occur near the base of the B1 Seam.

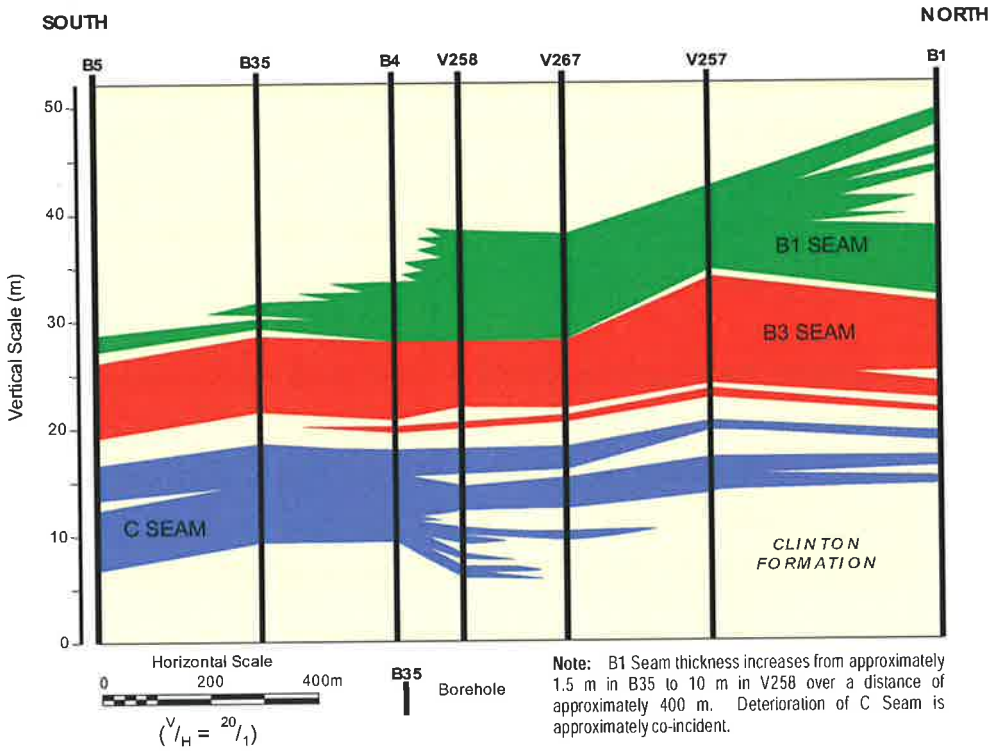



Figure 4.9 Seam variability in the Bowmans Deposit

Thin sand horizons (up to 0.15 m) develop locally within the B1 Seam, but are erratic and grade laterally into coal. Clastic sediments immediately surrounding and interfingering with the B1 Seam are mostly sands.

#### 4.3.1.5 Unnamed upper seams

Widespread coal formation ceased with the accumulation of B1 Seam. However, some thin, erratic and discordant seams develop locally above the roof of B1 Seam. The palynology of these younger coals indicates a possible Early Oligocene age (Harris, 1982).

### 4.3.2 Seam geometry, splitting and termination

The coals of the Bowmans Deposit are of significant areal extent (exceeding 150 $km^2$) and develop locally into thick and relatively consistent seams. However, in areas of multi-seam occurrence, extremely rapid changes in thickness and extensive splitting away from depocentres, together result in an irregular seam geometry. Seam splitting and bifurcation is prominent, typically along well defined axes, leading to progressive thinning and eventually termination (Figures 4.7 and 4.8).

Major splitting occurs along north-south and east-west axes, located to the west and south of seam depocentres, and appears unrelated to variations in underlying bedrock topography (Figures 4.7 and 4.8). These features in the B3 and B1 Seams, combined with abrupt terminations to the north and northeast near shallow bedrock, lead to an approximately concentric pattern of splitting away from depocentres. This is consistent with patterns reported by Esterle and Ferm (1986) for the transition from ombrogenous peat-forming interiors to peripheral topogenous settings.

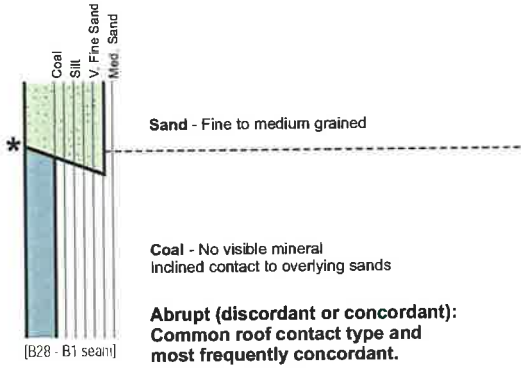
In general, seam splitting leads to development of sand-dominated interbeds, although silty intervals are common in the basal portion of B3 Seam. Furthermore, splitting and significant thinning are generally accompanied by increased mineral matter, such that thin seams may show a high mineral content throughout. While intraseam splitting normally leads to bifurcation, some thin (< 0.1 to 0.5 m) and localised clastic interbeds can occur entirely within seams.

### 4.3.3 Seam boundaries

The boundaries between the clastic and coaly lithofacies in the Bowmans Deposit are of two principal types (Table 4.2, Figure 4.10). The first is a sharp, sometimes irregular contact (suggesting no interaction between the respective depositional environments) whereas the second is a more transitional interface and includes a zone of limited and progressively diminishing interaction. The former is typical of roof contacts, while the latter commonly occurs at seam floor boundaries.

**Figure 4.10**
**SEAM BOUNDARIES - BOWMANS DEPOSIT**

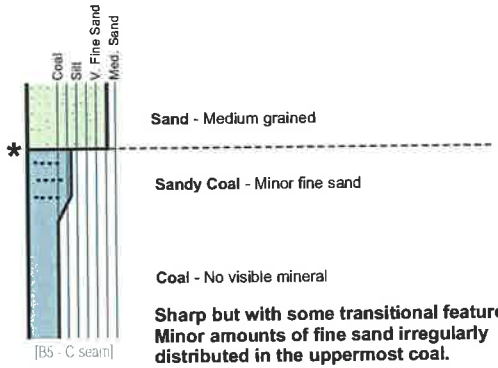
## ROOF CONTACTS




**Sand** - Fine to medium grained

**Coal** - No visible mineral
Inclined contact to overlying sands

**Abrupt (discordant or concordant):**
**Common roof contact type and most frequently concordant.**

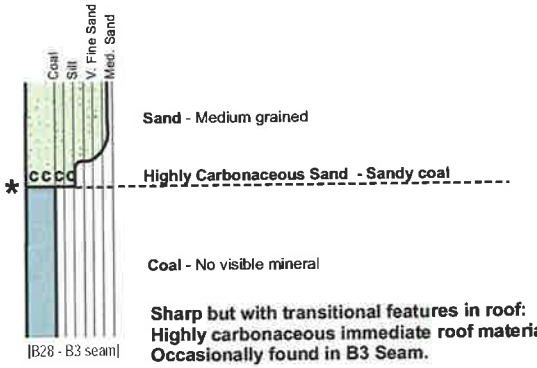



**Sand** - Medium grained

**Sandy Coal** - Minor fine sand

**Coal** - No visible mineral

**Sharp but with some transitional features in seam:**
**Minor amounts of fine sand irregularly distributed in the uppermost coal.**
**May occur in C and B1 Seams.**



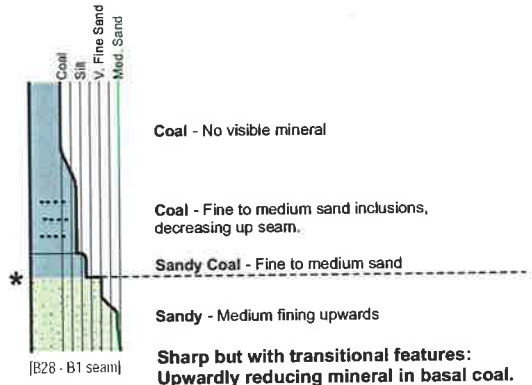

**Sand** - Medium grained

**Highly Carbonaceous Sand - Sandy coal**

**Coal** - No visible mineral

**Sharp but with transitional features in roof:**
**Highly carbonaceous immediate roof material.**
**Occasionally found in B3 Seam.**

## FLOOR CONTACTS



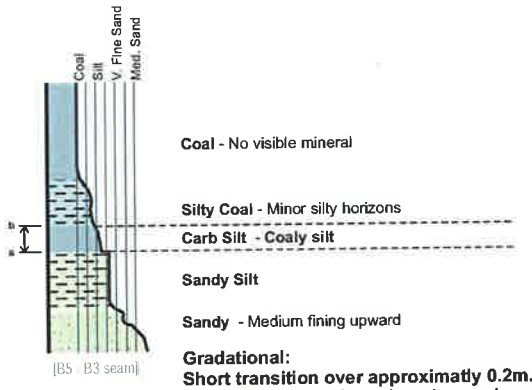

**Coal** - No visible mineral

**Coal** - Fine to medium sand inclusions, decreasing up seam.

**Sandy Coal** - Fine to medium sand

**Sandy** - Medium fining upwards

**Sharp but with transitional features:**
**Upwardly reducing mineral in basal coal.**
**Common and found on all Seam floors.**




**Coal** - No visible mineral

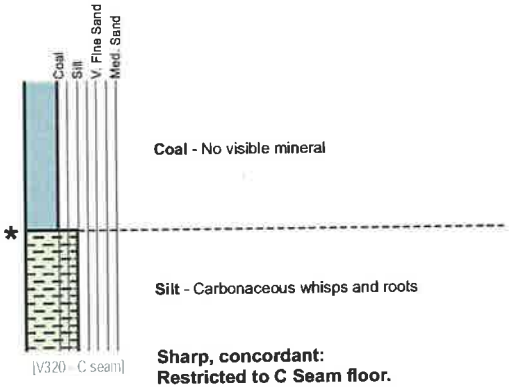
**Silty Coal** - Minor silty horizons

**Carb Silt - Coaly silt**

**Sandy Silt**

**Sandy** - Medium fining upward

**Gradational:**
**Short transition over approximatly 0.2m.**
**Upwardly decreasing mineral may also exist.**
**Restricted to B3 Seam floor.**




**Coal** - No visible mineral

**Silt** - Carbonaceous whisps and roots

**Sharp, concordant:**
**Restricted to C Seam floor.**

**LEGEND**

**Contact**

Contact position - sharp boundary

Transitional contact zone

**Lithology**

Silt (variable carbonaceous content)

Sand (variable carbonaceous content)

Coal

Table 4.2 Seam boundary characteristics in the Bowmans Deposit

| Seam Interface | Nature of Contact | | | Adjoining Clastic Sediment | Transitional Features |
|---|---|---|---|---|---|
| | Rate of Change | Type | Relationships | | |
| B1 Roof | Abrupt | Angular | Discordant | Fine to medium sand | None |
| B1 Floor | Abrupt | Regular | Concordant | Fine to medium sand | Fine sand in basal 0.25-1.1 m |
| B3 Roof | Abrupt | Possibly regular | May show both concordant and discordant | Sand and carbonaceous sand | None |
| B3 Floor | Gradational (to abrupt) | Regular | Concordant | Laminated silty sand/silty coal | Mineral in basal 0.1–1.0 m |
| C Roof | Abrupt | Possibly regular | Possibly discordant | Fine to medium sand | None |
| C Floor | Abrupt (to rapid gradation) | Regular | Concordant | Silt | Mineral in basal 1.0-1.75 m |

An abrupt, concordant floor boundary is typical of the C and B1 Seams, while the B3 Seam commonly shows a rapid gradation from highly carbonaceous silt, to silty coal over approximately 0.2 m (Figure 4.10). However, while the change from clastic-dominated to organic-dominated accumulation is commonly sharp in C and B1 Seams, transitional features reflecting ongoing overbank sedimentation (i.e. fine quartzitic sand) also occur and persist over intervals extending from 0.1 m to 2 m above the seam boundary. The combination of a relatively sharp contact, with ongoing, albeit limited and progressively diminishing mineral input up sequence, could be considered a stepped/transitional interface and is the most widely recognised floor boundary (Figure 4.10). The floor contacts of sub-seams display similar characteristics to those of the major seams.

Mineral matter within the basal section of the seam typically occurs as irregularly distributed, fine-grained sand, possibly reflecting some mixing with the overlying peat. Finely laminated intervals are occasionally detected. In thicker developments, a progressive decrease in sand abundance or lamination frequency away from the contact is discernable.

Roof contacts are in all cases abrupt against fine to medium-grained sand and occasionally show angular discordance (Figure 4.10). Definitive identification of erosional boundaries is limited to the B1 Seam where closely spaced observation points are available in the trial pit excavation. At this site, the seam roof shows vertical fluctuations of up to 3 m over a lateral distance of approximately 50 m (Figure 4.11). Transitional features are usually absent, although thin horizons (i.e. up to 0.1 m) of highly carbonaceous sediment have been detected. The uppermost portion of major seams is typically represented by coal devoid of any obvious mineral enrichment.

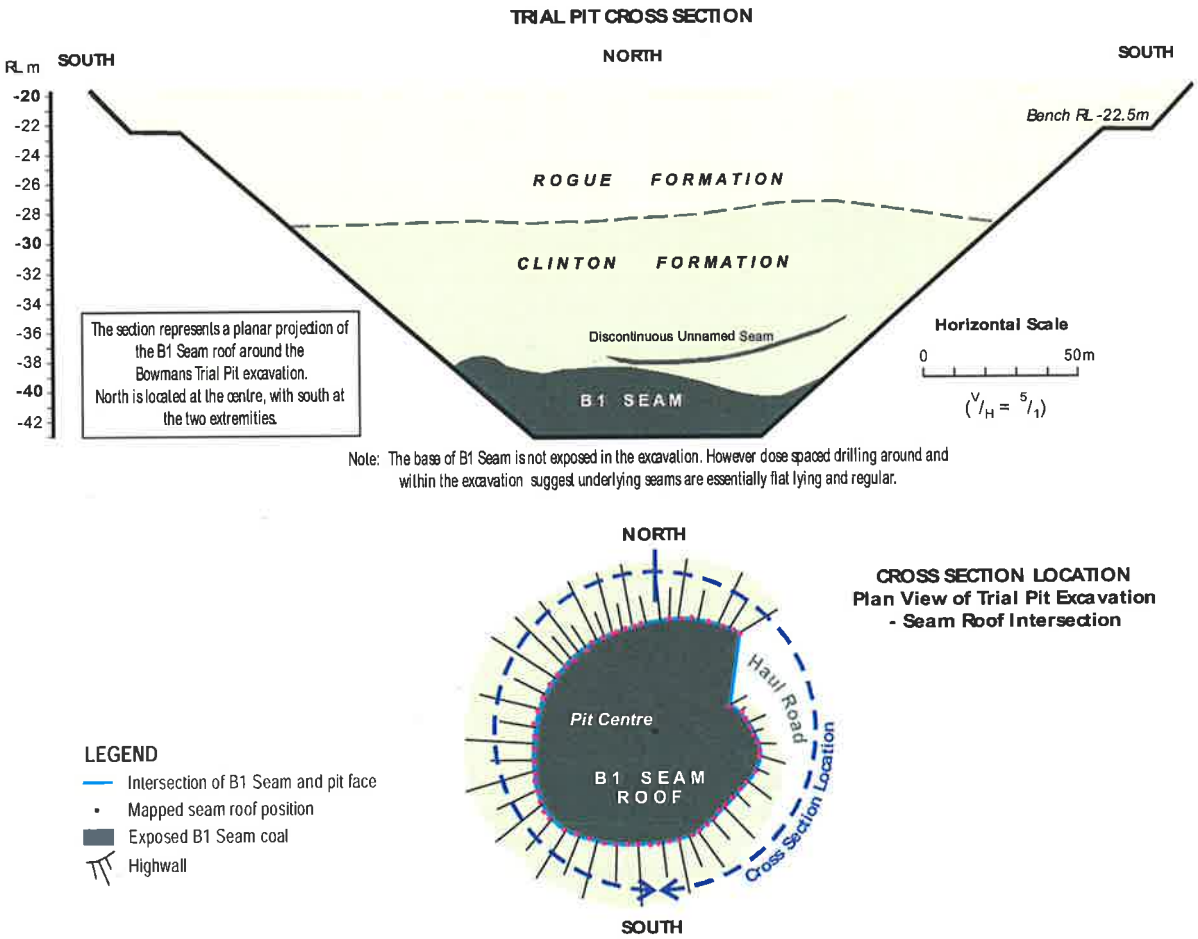



Figure 4.11 B1 Seam roof variation in the Bowmans Trial Pit

## 4.4 THE LOCHIEL COAL DEPOSIT

### 4.4.1 Coal occurrence and seam characteristics

A number of thin coal seams, (mostly between 0.5 and 2 m) showing limited lateral extent occur in the lower portion of the Bumbunga Sand Formation. However, thicker and more consistent coals are restricted to the Kooliata Coal Member. Here three seams, termed H Seam, G Seam and F Seam in ascending stratigraphic order, are developed (Figure 4.12). These horizons typically range in thickness from 2 to 6 m and exhibit a regular architecture. The lowermost H Seam and uppermost F Seam are restricted to the northern and central portions of the deposit, while G Seam representing the most extensive phase of coal accumulation, occurs throughout the area and onlaps shallow basement in the south and east.

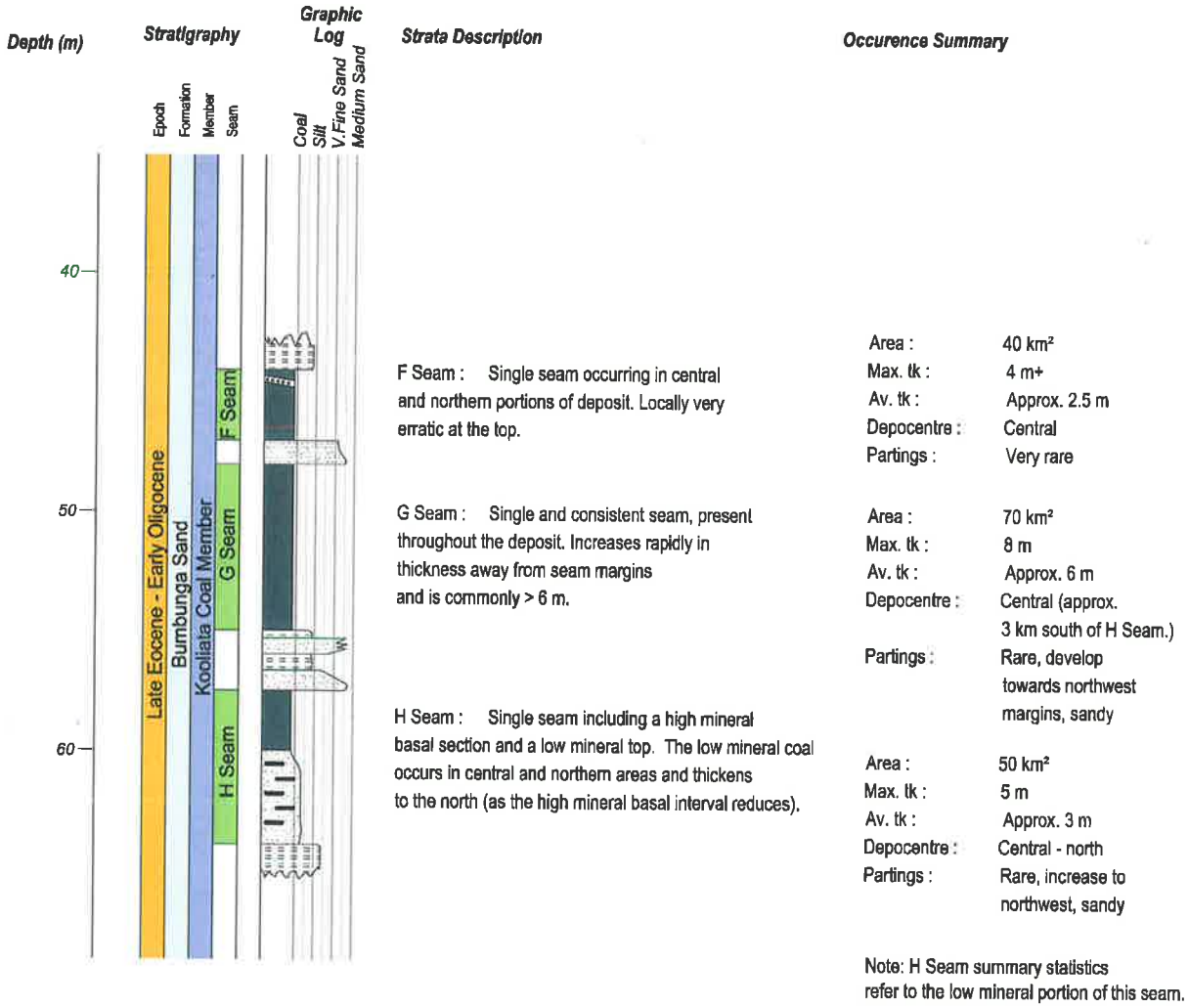



Figure 4.12 Coal stratigraphy of the Lochiel Deposit

### 4.4.1.1 H Seam

H Seam occupies a north-south orientated, ovoid area of some 11 km by 5 km and spans the central and northern portions of the deposit. While thickness tends to increase in an approximately radial manner, maximum coal development exceeding 5 m, occurs in the north (Figure 4.13), reflecting concurrent fan delta and fluvial sedimentation in the south (Kremor, 1992).

Clastic partings are generally absent, with thin, locally developed interbeds limited to the near vicinity of the seam's western and northern margins (Figure 4.14). However, disseminated mineral matter is abundant throughout much of the seam and both lateral and basal boundaries are gradational into coaly sands and carbonaceous sands. The sandy basal portion of the seam

is especially pronounced in the south where overbank influence was greatest, diminishing up sequence as fluvatile sedimentation prograded southwards.

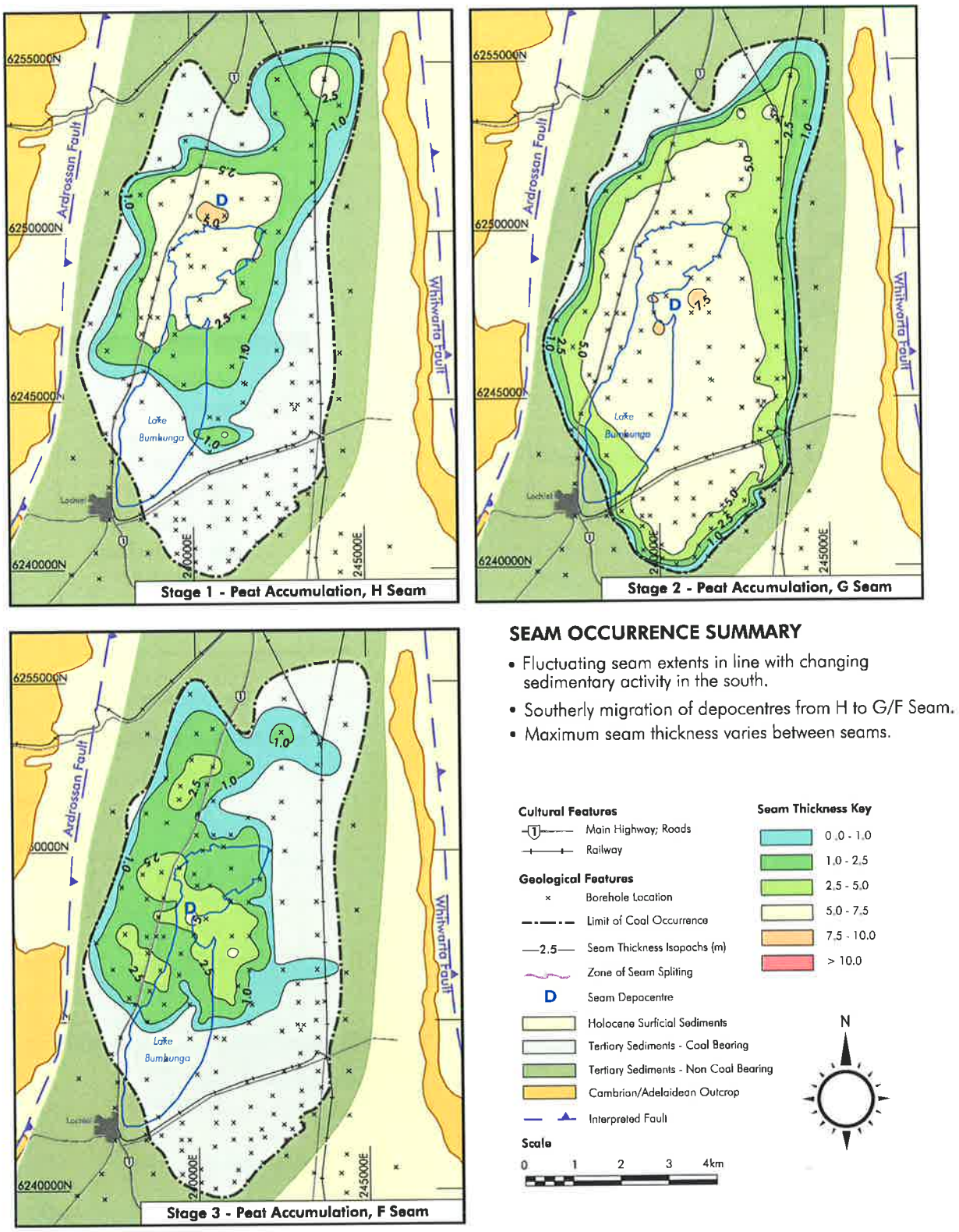



Figure 4.13 Seam occurrence and characteristics in the Lochiel Deposit

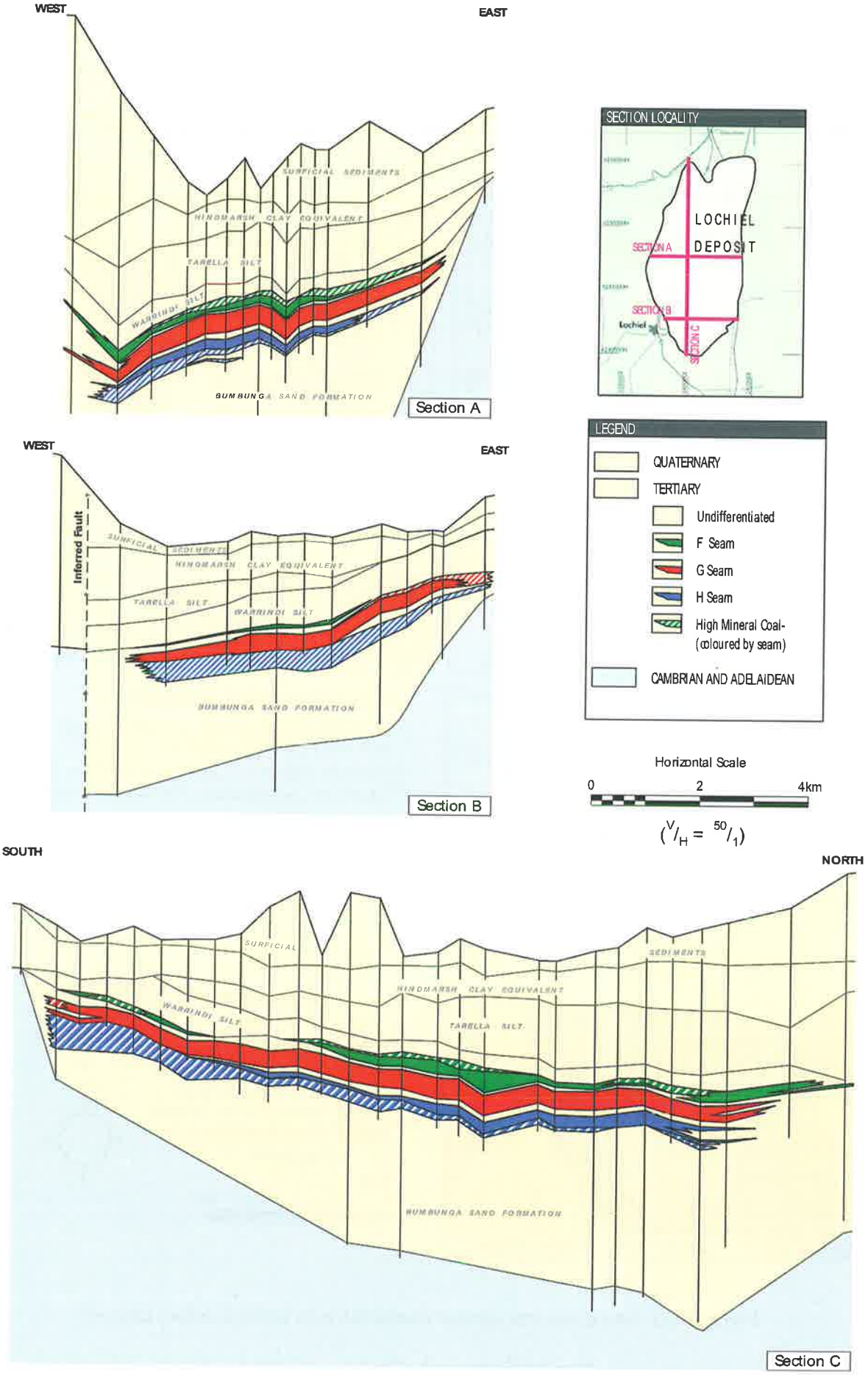



Figure 4.14 Representative cross sections through the Lochiel Deposit

#### 4.4.1.2 G Seam

The G Seam is the most extensive and thickest coal in the Lochiel Deposit. It too forms a north-south orientated, ovoid accumulation and is approximately 14 km by 7 km in extent. The seam typically overlies silt, grading to sand at the seam margins. Thickness of this seam is very consistent over much of the area, commonly exceeding 6 m and attaining 8 m in the centre of the deposit (Figures 4.13 and 4.14).

G Seam is generally represented by a single coal horizon with splitting largely restricted to its margins where minor, local partings develop. Slightly more extensive clastic interbeds occur along the northwestern margin. Associated with peripheral thinning is a rapid lateral increase in mineral matter, whereby coal grades into carbonaceous sand. The pattern of G Seam deposition appears similar to that in the underlying Condowie Silt Member (as described by Kremor, 1992).

#### 4.4.1.3 F Seam

The distribution of F Seam resembles that of H Seam, with coal development in the northern and central areas, over an area of approximately 10 km by 4 km. Maximum coal accumulation (i.e. exceeding 4 m) more or less coincides with the G Seam depocentre (Figure 4.13 and 4.14). However, seam thickness has been modified by partial and irregular combustion of the upper peat surface, resulting in abrupt local variations of thickness (Figure 4.15). Although rare, localised seam thickening also occurs.

F Seam typically occurs as a single coal interval with splitting restricted to the periphery of the deposit, especially in the west. Away from its margins, clastic interbeds are thin and very localised. Thinning is accompanied by an increase in mineral matter and coal grades laterally into carbonaceous sand. The upper portion of the seam (and immediately overlying sediments) in places appear weathered.

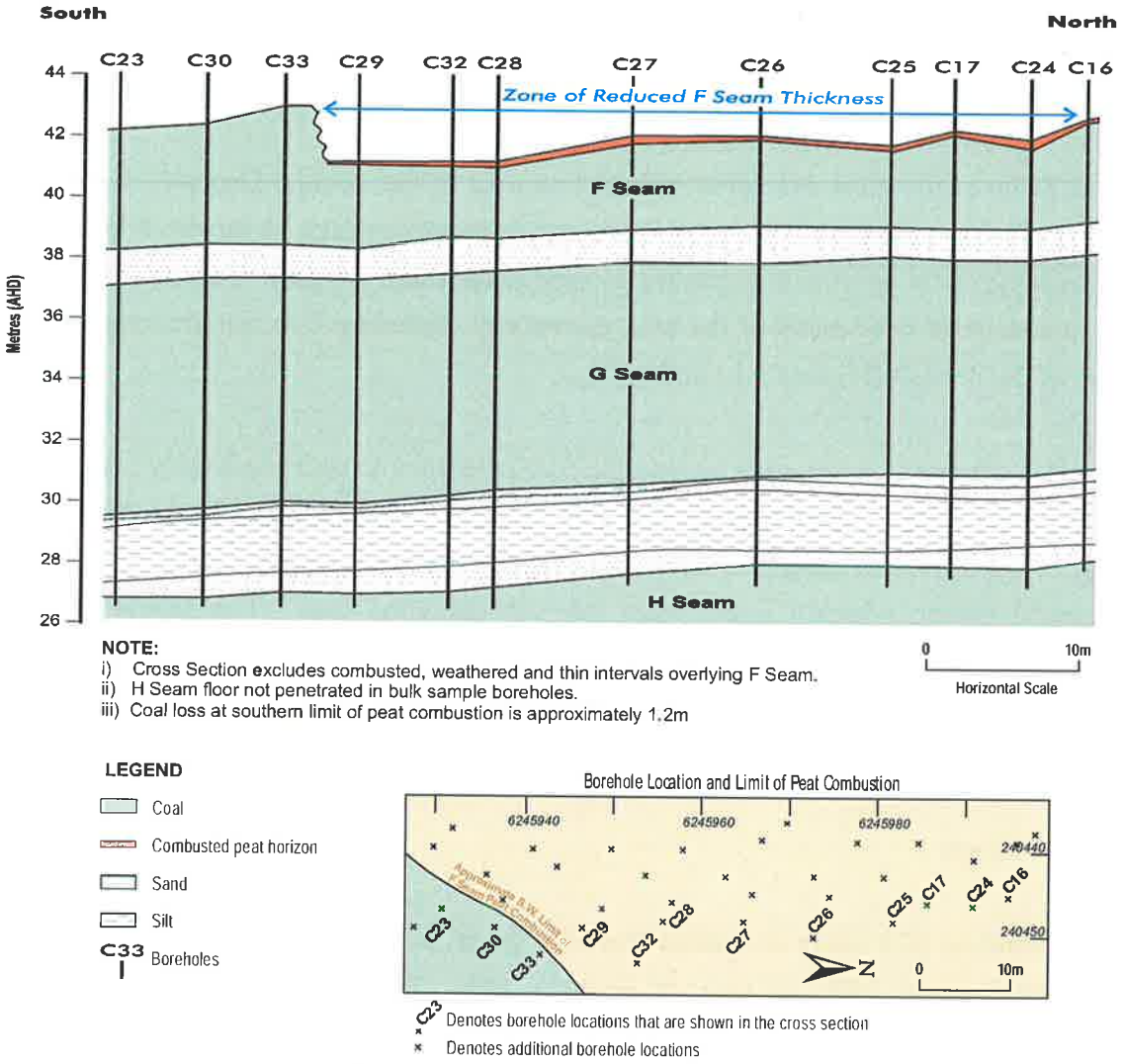



Figure 4.15 Irregular F Seam roof at a bulk sampling site in the Lochiel Deposit

### 4.4.2 Seam geometry and termination

Seams within the Lochiel Deposit are characterised by a relatively consistent geometry, displaying an approximately lensoidal form and radial thinning towards their margins (Figure 4.14). Variations in thickness are most pronounced near seam margins and the depocentres typically coincide with the geographic centres of seams. Otherwise seams are relatively consistent across the deposit.

Seams are essentially free of clastic interbeds except near their outer margins, where rapid local splitting can occur, especially in the H and G Seams. This is accompanied by an increase in mineral matter and seams terminate via lateral facies change to coaly and carbonaceous sand. An increased tendency for splitting is evident along the western margin of the deposit, possibly reflecting local sediment input associated with uplift along the Ardrossan Fault.

### 4.4.3 Seam boundaries

A variety of boundary types are evident in the coals at Lochiel, ranging from very gradational to abrupt and erosional (Table 4.3; Figure 4.16). In general, the most gradational contacts mark the initiation and cessation of coal accumulation (i.e. H Seam floor and F Seam roof, respectively), less gradational characteristics develop on other floor contacts and abrupt contacts are common on the remaining seam roofs. However, local departures from this pattern exist, particularly near the outer margins of the deposit, (especially in the south) and on the F Seam roof where multiple contact types occur.

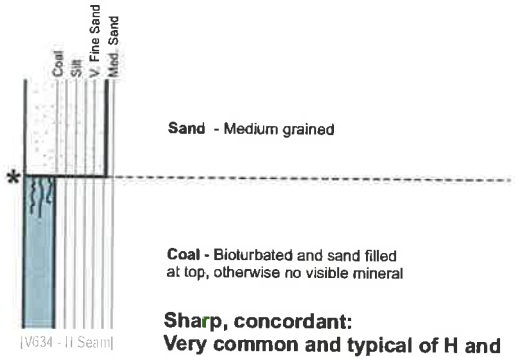
Table 4.3 Seam boundary characteristics in the Lochiel Deposit

| **Seam Interface** | **Nature of Contact** | | | **Adjoining Clastic Sediment** | **Transitional Features** |
|---|---|---|---|---|---|
| | **Rate of Change** | **Type** | **Relationships** | | |
| F Roof | (i) Abrupt | Angular | Discordant | Fine sand, carbonaceous silt | None |
| | (ii) Very gradational/ Stepped | Regular | Concordant | Carbonaceous silt | Finely disseminated silt and clay |
| | (iii) Abrupt | Regular | Appears concordant | Sand | None * |
| F Floor | Gradational (sometimes sharp) | Regular | Concordant | Laminated fine sand and coal | Decreasing sand up over basal 0.6 m of seam |
| G Roof | Abrupt (some transitional features ) | Regular (to angular) | Concordant (to discordant) | Very fine to medium sand | None * |
| G Floor | Gradational (to abrupt) | Regular | Concordant | Silt, variably carbonaceous | Minor mineral in basal seam 0.1 m |
| H Roof | Abrupt | Regular to irregular | Concordant to discordant | Very fine to medium sand | None |
| H Floor | Very gradational | Regular | Concordant | Coaly sands and sandy coal | Gradual upward reduction in fine sand/silt |

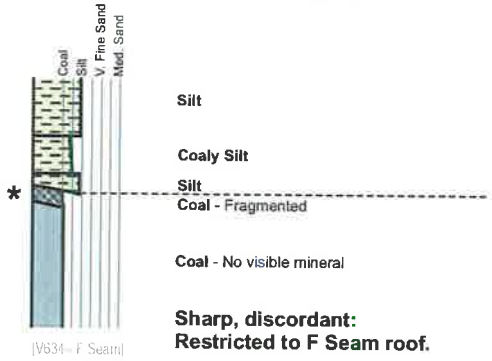
Key: * Increased mineral common toward lateral seam margins

## Figure 4.16
## SEAM BOUNDARIES - LOCHIEL DEPOSIT

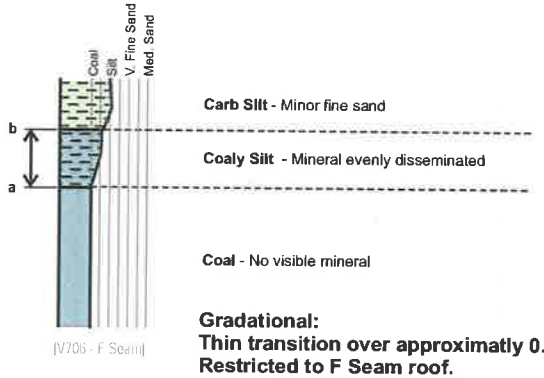
### ROOF CONTACTS




**Sharp, concordant:**
**Very common and typical of H and G seam roofs.**

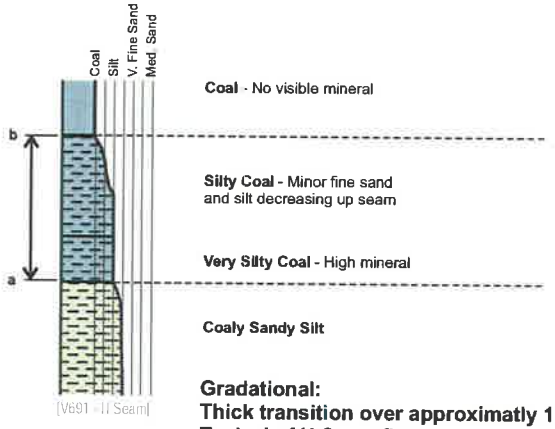



**Sharp, discordant:**
**Restricted to F Seam roof.**

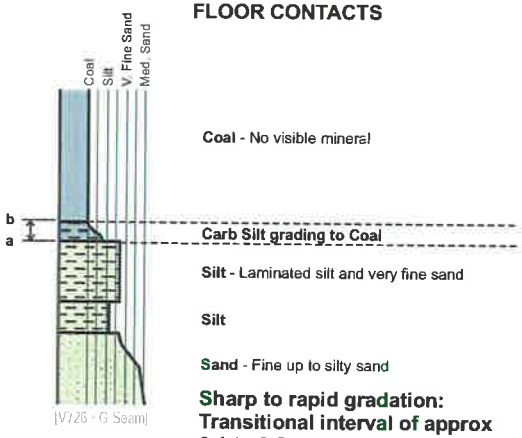



**Gradational:**
**Thin transition over approximatly 0.5m.**
**Restricted to F Seam roof.**

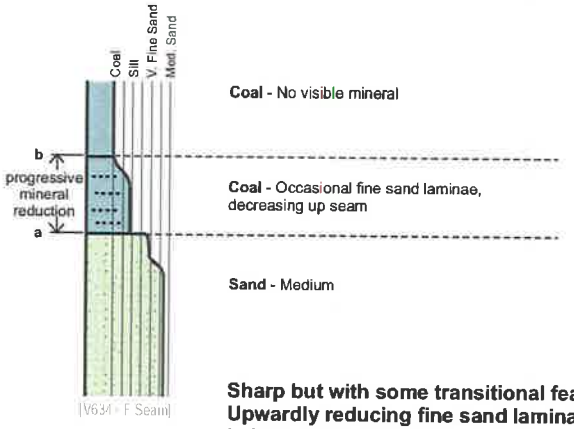
### FLOOR CONTACTS




**Gradational:**
**Thick transition over approximatly 1.5m**
**Typical of H Seam floor.**




**Sharp to rapid gradation:**
**Transitional interval of approx**
**0.1 to 0.2m. Typical of G Seam floor.**




**Sharp but with some transitional features.**
**Upwardly reducing fine sand laminations**
**in basal coal. Typical of F Seam floor.**

**LEGEND**

**Contact**

- Contact position - sharp boundary
- Transitional contact zone

**Lithology**

- Silt (variable carbonaceous content)
- Coal
- Sand (variable carbonaceous content)

Seam floor contacts are typically regular and concordant, with some degree of gradation evident (Figure 4.16). The most transitional features occur in the H Seam where mineral content (i.e. fine sand and silt laminations and disseminations) progressively decrease over a vertical interval of 2 to 3 m. The G and F Seam floor contacts commonly exhibit some gradational features, such as a floor of thin carbonaceous silt and an interval of sand laminae over the basal 0.2 to 0.6 m of the seam, respectively. The latter vary from regular laminae of fine sand 1 to 3 mm thick near the seam floor to isolated disseminations. Minor silt enrichment may also occur over the basal 0.1 m of G Seam. However, in both G and F Seams readily definable boundaries exist between clastic-dominated and organic-dominated sediments.

Roof contacts vary from very gradational to abrupt, with the latter being most common, while their form varies from irregular and discordant, to concordant (Figure 4.16). The H Seam and G Seam roof contacts are generally abrupt, against very fine to medium grained sands, with coal immediately below the roof free of mineral matter (other than within bioturbations). Boundaries can undulate slightly, with amplitudes of approximately 0.2 m. However, significant peat erosion appears rare and close spaced observation sites suggest generally regular contacts (Figure 4.15). In F Seam two distinct types of roof boundary are common, one transitional and the other sharp, angular and discordant. The former occurs over vertical intervals up to 1 m, whereby coal grades into coaly and carbonaceous silts, marking the end of coal accumulation in the Kooliata Coal Member (Figure 4.16). Within this sequence, brief reversals to mineral-poor, coaly intervals may occur across boundaries that are characteristically regular and concordant. The discordant boundaries are marked by a thin band (0.05-0.3 m) of hard, fragmented coal, which is commonly overlain by fine sand and carbonaceous silt and varies significantly over short distances (Figure 4.15). A third, uncommon F Seam roof boundary type is represented by an abrupt, concordant contact.

Roof contact conditions may change in the immediate vicinity of the outer margin of the deposit. For example in F Seam a sharp regular boundary develops, while in G Seam the upper portion of the seam (i.e. up to 1.5 m) may be enriched in fine sand, as in basal H Seam coals. Significant changes in mineral content also occur in the proximity of seam margins (Figure 4.17).

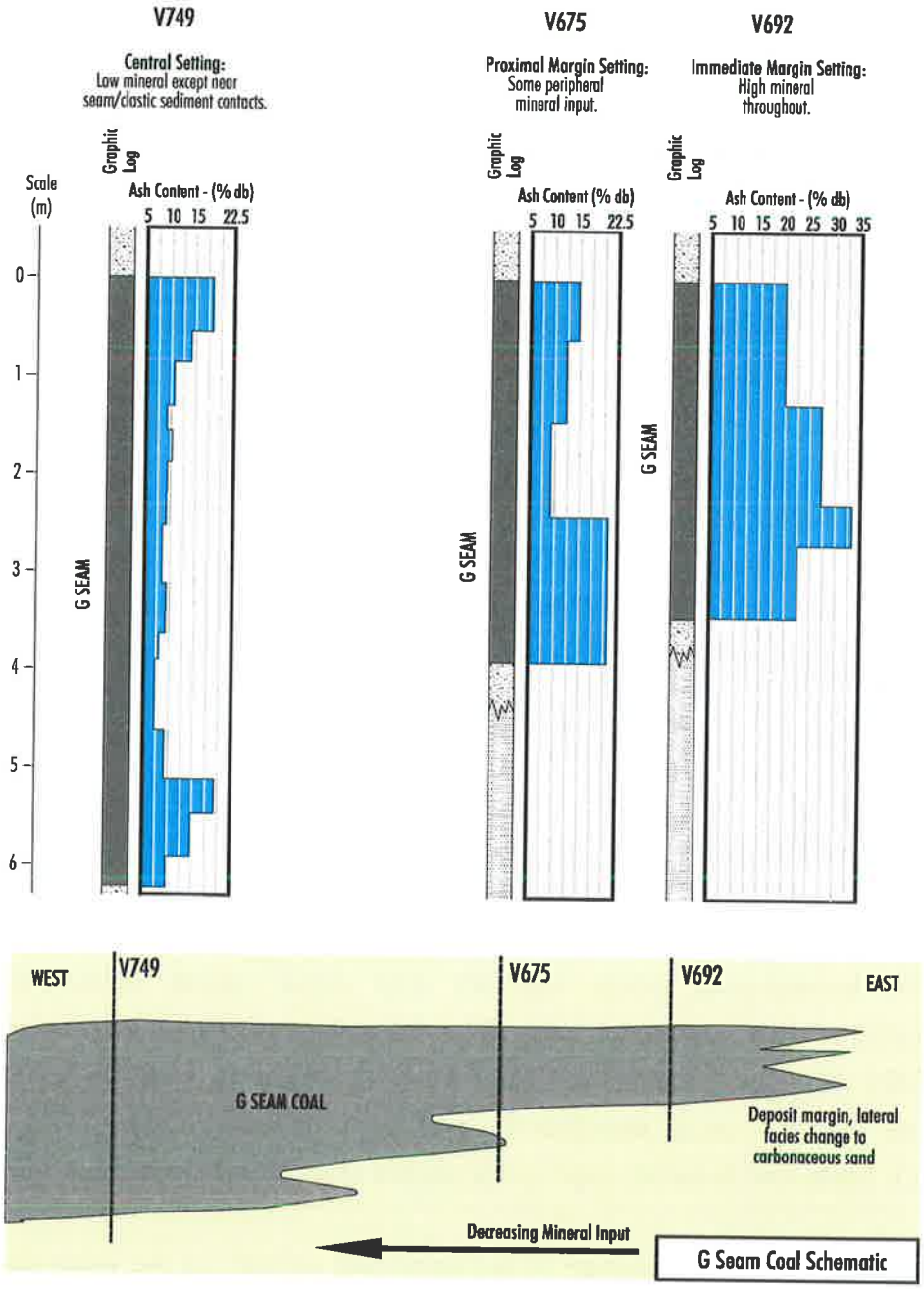



Figure 4.17 Lateral variation in ash and mineral contents with respect to seam margins

## 4.5 COAL FORMING CONDITIONS IN THE NORTHERN ST. VINCENT BASIN

### 4.5.1 Bowmans Deposit

#### 4.5.1.1 Coal distribution and clastic sedimentation

***Seam migration and restriction***

Changing patterns of coal occurrence and clastic sedimentation in the Bowmans Deposit suggest gradual variations in depositional conditions over the period of peat formation. A major up-sequence decrease in the areal extent of each seam is particularly pronounced, from approximately 150 $km^2$ in C Seam, through 70 $km^2$ in B3 Seam, to 30 $km^2$ in B1 Seam, and is accompanied by a progressive northward restriction of coal accumulation (Figure 4.7). Migration of seam depocentres is also evident, with a northerly shift of approximately 1 km from C Seam to B3 Seam and a westerly migration of approximately 1 km between the B3 and B1 Seams. Significantly, while such spatial variations exist between seams, the maximum coal development is similar (i.e. 10 m to 12 m) and all northern depocentres occur in reasonably close proximity to the inferred Bowmans Fault.

Paralleling the up-sequence change in coal distribution is an increasingly variable seam architecture. The lowermost coal zone (i.e. C Seam) typically thins in a regular manner, with generally minor clastic interbeds and significant splitting restricted to the outer limits of the deposit and the northeastern bedrock high. B3 Seam is less uniform, being prone to increased splitting and thinning and, except for a relatively limited area, is thus represented by multiple sub-seams. The uppermost seam (B1 Seam) changes rapidly over short distances, and typically consists of multiple sub-seams except for a small area in which they coalesce.

Additional up-sequence variation is also evident in the nature of its clastic sediments. Those underlying C Seam and separating the C and B3 Seams, contain significant intervals of silt which commonly constitute the seam floor. Silty interbeds are also typical of the lower portion of B3 Seam. However, above B3 Seam sand predominates and forms the bulk of the clastic sediment associated with the B1 Seam.

***Contemporary sedimentation, depocentres and seam attributes***

Peat in the Bowmans Deposit is interpreted to have accumulated within interchannel settings. Based on its seam distribution and splitting, fluvial systems are inferred in the west near the present head of Gulf St. Vincent, draining off elevated bedrock in the north; and possibly also to the south, draining from the east northeast (Figure 4.18). These appear to have migrated

northward with time, significant affecting the distribution (progressive northward restriction) and seam characteristics (increased splitting to the south) of the peat. The progressive decrease in flood-basin sediment relative to channel deposits also results in increasingly variable coal characteristics up sequence, especially the degree of seam splitting.

The most significant and consistent site of coal accumulation is an inferred half graben to the west of the Bowmans Fault and a prominent basement high. The latter may have been a site of non-deposition during this period and would have impeded fluvial encroachment from the east. This, together with local subsidence, resulted in an area of optimum peat accumulation and preservation. Coal development in this manner is consistent with the findings of Cooper (1985), who reported a close relationship between local tectonics and depocentres within the St. Vincent Basin. Progressive onlap over the pre-Tertiary bedrock suggests that most displacement predated coal formation. The slight migration of seam depocentres possibly reflects differential compaction, whereby the thickest peat pile underwent the greatest consolidation (leading to increased susceptibility to overbank sedimentation), while less consolidated areas maintained peat accumulation, as observed in the Tertiary coal measures of the Latrobe Valley (Holdgate *et al.*, 2000).

Splitting appears to have been controlled largely by sedimentological factors and, in particular, contemporaneous fluvial activity, whereby peat accumulation was rapidly replaced by overbank sediment allowing gradual re-establishment of vegetation and lateral peat progradation. This style of splitting fits with the "sedimentary splitting" mechanism reported by Ward and Swaine (1995) and is typical of fluvial deposits (Fielding, 1985). Extensive splitting near basement highs is possibly more complex and may reflect the interface between differing subsidence regimes, wherein local clastic input resulted in unfavourable conditions for peat accumulation and preservation. Stuart (1969) reports that in many parts of the basin coal zones end abruptly against faults, without re-appearing on the upthrown side.

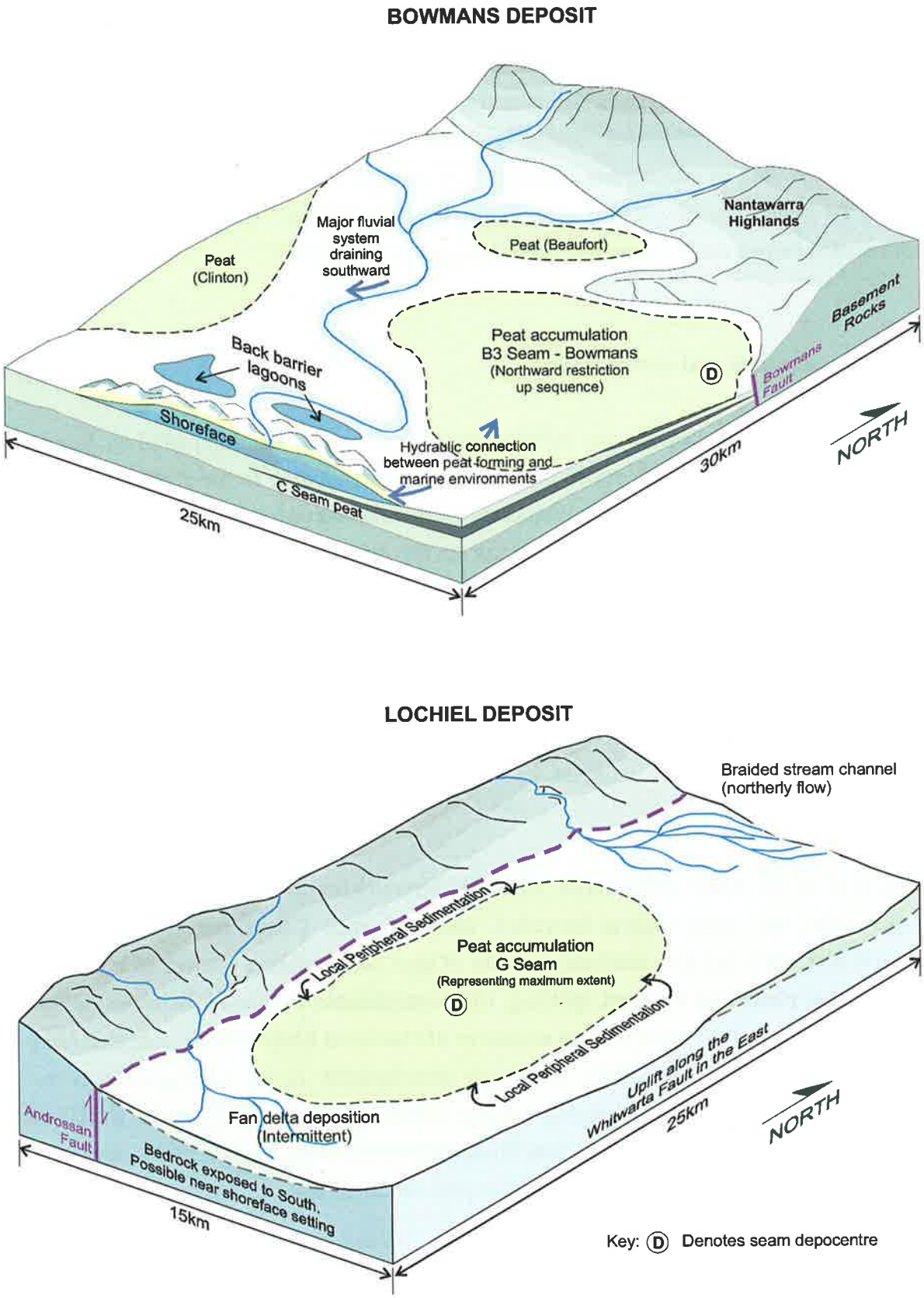



Figure 4.18 Palaeogeographic reconstructions of the Bowmans and Lochiel Deposits

Vertical transitions from clastic to organic sedimentation (i.e. seam floors) are suggestive of a relatively rapid onset of peat formation, but with prolonged and gradually diminishing overbank input, reflected by the progressive upward decrease in mineral content through the seam. A number of possibly interrelated mechanisms may be involved, including waning of

fluvial influence by channel migration to more distal locations; steady elevation of the peat surface making it less prone to overbank inundation; and development of dense vegetation in peripheral settings that acted as a sediment trap. In contrast, roof boundaries are suggestive of a distinct palaeoenvironmental change whereby peat formation is replaced by overbank sedimentation and, in some cases, channel incision and deposition of fluvial sands. At the roof of B1 Seam, significant peat erosion, in places exceeding 7 m is indicated (assuming a 2.5:1 peat to brown coal compaction ratio; Holdgate *et al.*, 1995).

#### 4.5.1.2 Synopsis of coal accumulation

Within the Bowmans Deposit the initial phase of basin infill was dominated by fluvial and lacustrine sedimentation with occasional thin peats accumulating in pre-existing topographic lows and fault-bound depressions. Progressive terrestrialisation[1], possibly combined with the maintenance of distal channel belt settings to the west and south, ultimately led to the development of conditions suitable for sustained and widespread peat formation (i.e. C Seam). This phase was largely uninterrupted by clastic deposition, with the exception of short-lived crevasse splays or minor floodplain sedimentation. Peat accumulation was relatively consistent, although distinct depocentres developed in the south and northeast, with the latter occupying a position immediately west of the inferred Bowmans Fault. The accumulation of C Seam peat was rapidly terminated by overbank sedimentation, possibly associated with channel belt migration.

Deposition of B3 Seam commenced following terrestrialisation of lacustrine environments formed within the clastic interval between C and B3 Seams. Contemporary sedimentation in the west and south led to a northward retreat of peat accumulation relative to the preceding peat forming phase and frequent splitting, with considerable oscillation between fluvial and organic processes. Peat accumulation exclusive of clastics is limited to the northeast (near the inferred Bowmans Fault), where maximum development is of a similar order to the underlying seam. Palynological studies reveal a hiatus in peat deposition within the B3 Seam, from Middle – early Late Eocene to Late Eocene (Meakin, 1985; Stoian, 2003). Avulsion and floodplain sedimentation terminated B3 Seam peat accumulation.

In the northern part of the deposit clastic sedimentation was sufficiently restricted for a rapid resumption of peat accumulation, while elsewhere fluvial activity continued. Nearby fluvial processes are highlighted by overbank incursion in the early phase of B1 Seam deposition and frequent splitting throughout the seam. Continuous peat accumulation is very limited, with maximum development around the geographic centre of the B1 Seam. Westerly migration of

[1] Terrestrialisation is the process whereby a water body silts up to allow the formation of peatlands (Diessel, 1992).

the depocentre (relative to B3 Seam) may signal diminished subsidence along the inferred Bowmans Fault. The peat deposited during this phase hosts increasing (albeit low) levels of marine dinoflagellates. Together with very rapid seam thinning and splitting to the south, this suggests an approximately east-west oriented channel and/or shoreline setting. Avulsion and channel encroachment terminated peat accumulation and resulted in significant peat erosion, while ongoing clastic sedimentation precluded further substantial coal formation in the Clinton Formation.

### 4.5.2 Lochiel Deposit

#### 4.5.2.1 Coal distribution and clastic sedimentation

While the regional extent of peat formation and the nature of the transitions between clastic and organic facies changed over time in the Lochiel Deposit, its gross seam characteristics are relatively static, with the amount of overbank sedimentation in the south being the main variable. The seam depocentres are centrally located, although successive seams migrate slightly to the south and the extent of major coal development (i.e. approaching maximum seam thickness) expands, notably from Seam H to Seam G. These features are possibly due to a combination of differential compaction and the diminishing influence of clastic sedimentation in the south.

The regular, lensoidal seam geometry, in which splitting is confined to the seam margins and the lateral facies change is to sandy sediments, reflects vertical accretion and relatively uniform sedimentation. Furthermore, the consistency of sedimentary architecture between seams, and more broadly between peat accumulation (especially G Seam) and the underlying lacustrine sediments of the Condowie Silt Member, suggests a persistent tectonic influence on the sub-basin. In particular, movement along basement faults appears to have been the primarily control on the nature and cyclicity of deposition.

Peat accumulated within the Lochiel Sub-basin in an approximately central setting during periods of limited, or regionally restricted clastic sedimentation. Kremor (1992) identified a fan delta system in the south draining uplifted areas west of the Ardrossan Fault as the most significant source of clastic sediment during deposition of both H and F Seams. In H Seam southerly peat progradation is evident as this system gradually diminished, while in F Seam peat accumulation is limited to the central and northern areas. Alternatively, during G Seam a period of relative sediment starvation resulted in widespread peat formation across the sub-basin (Figure 4.18). Throughout the period of peat accumulation additional locally sourced sediment is likely to have been introduced by runoff from exposed bedrock in the west, south

and east, leading to peripheral mineral input, lateral facies change and localised splitting in each of the seams.

Vertical transitions from clastic to organic sedimentation vary with the nature and extent of contemporary sedimentation. In H and F Seams contacts are gradational suggesting that fan delta and overbank sedimentation persisted and regularly inundated the peat bog, especially in the south. Conversely, in G Seam where peat accumulation encroached upon a shallow lacustrine setting, a relatively abrupt change occurs. Roof contacts are typically sharp, (especially in H and G Seam), signalling a rapid change to widespread fan delta and floodplain sedimentation, while in F Seam a gradational boundary commonly occurs in line with progressively increasing groundwater levels and clastic input.

#### 4.5.2.2 Synopsis of coal accumulation

Sustained peat formation in the Lochiel Sub-basin followed a period of extensive fan delta floodplain and lacustrine sedimentation. It commenced with the widespread development of H Seam peats. In the central and southern areas these were regularly invaded by overbank sediment, although such incursions gradually diminished and retreated southward. Other factors such as the growth of peripheral forests that acted as a sediment trap, and a tendency toward ombrogenous conditions, may also have contributed to the exclusion of allochthonous mineral matter. The gradual decline in clastic input to this seam is reflected in its indistinct lower boundary and a thick basal interval of sandy and silty coal. Elsewhere the lateral margins of H Seam show peripheral enrichment in mineral matter in line with local clastic input. Rapid subsidence, possibly associated with movement along the Ardrossan Fault, led to abrupt termination of H Seam peat formation and the establishment of restricted floodplain and lacustrine environments (Kremor, 1992).

Terrestrialisation, possibly accompanied by a drop in the regional groundwater level initiated a second period of sustained peat accumulation that resulted in G Seam. This was a time of relative sediment starvation, allowing peat accumulation to extend across the sub-basin. Development of ombrogenous conditions may have further limited clastic input. In peripheral peat swamp settings runoff from nearby exposed areas resulted in lateral facies change to coaly and carbonaceous sand and local seam splitting. A rapid, possibly tectonically induced transition to delta fan deposition marked the end of G Seam peat accumulation, (Kremor, 1992).

Peat formation in F Seam resumed over the central and northern areas, albeit with periodic but progressively decreasing siliciclastic influx. In the south fan delta and floodplain sedimentation generally precluded peat occurrence, although high mineral equivalents are

locally developed. Evidence exists for fluctuating, possibly tectonically-induced groundwater regimes during the latter phase of F Seam deposition, whereby organic accumulation was interrupted leading to exposure and partial combustion. Ultimately a gradual change in groundwater conditions lead to a transition from organic-dominated peat-forming environments, to open-water inorganic-dominated sedimentation, concluding coal formation in the deposit.

### 4.5.3 Regional coal forming conditions

Although in close geographic proximity and occurring within similar sedimentary sequences of comparable age, the coals of the Lochiel and Bowmans Deposits differ in many important respects, suggesting considerable differences in their respective palaeoenvironmental settings (Table 4.4). At Bowmans, the coal seams display rapid splitting away from their depocentres and typically along well defined axes; seam thickness and characteristics can vary considerably over short lateral distances; and seam termination is achieved principally by splitting. In contrast, the Lochiel seams have a regular, lensoidal form and increase in thickness toward their geographic centre. Splitting is limited to the immediate vicinity of their outer margins; and seams terminate principally by lateral facies change involving increased mineral contents.

Table 4.4 Comparison of seam attributes across deposits

| Parameter | Bowmans Deposit | Lochiel Deposit |
|---|---|---|
| Geometry | Rapid variation and extensive splitting | Consistent, lensoidal form |
| Lateral seam boundaries | Thinning and splitting | Increased mineral matter, local splitting and lateral facies changes |
| Distribution | Northerly restriction up sequence | Broadly consistent. Variable sedimentation in south. |
| Depositional consistency | No repetition or cyclic patterns in sedimentation. Dynamic. | Repetition of sedimentary pattern. Static. |
| Sedimentary setting | Unrestricted. Mostly fluvial dominated and increasingly so up sequence. | Restricted. Fluvial-dominated at commencement and lacustrine-dominated at conclusion |

Coal distribution also differs between the two deposits. At Bowmans there is a wide variation in coal development, whereby seams are reduced in areal extent and become progressively restricted to the north up sequence. Adjacent sediments show a tendency toward fluvial-dominated lithofacies, which is paralleled by increased seam variability. Conversely, successive seams in the Lochiel Deposit have a relative static regional extent and their characteristics and associated sediments reflect increasingly lacustrine conditions. Other differences between the deposits are apparent in depositional patterns through the coal-bearing interval. In particular, interseam sediments and some of the coal seams at Lochiel exhibit similarities to the underlying lacustrine sediments, while repetitive patterns are not

evident in the predominantly fluviatile Clinton Formation at Bowmans. Collectively these interdeposit variations are suggestive of a relatively dynamic sedimentary setting at Bowmans compared to a more stable environment at Lochiel.

Broad expanses of interchannel, flood-basin peat accumulated in a paralic setting at Bowmans, where either stable barrier systems or a landward location protected the area from direct marine inundation (Figure 4.18). While the architecture of the Bowmans Deposit (i.e. seam geometry, splitting and termination) is consistent with contemporaneous fluvial activity and floodbasin deposition, the presence of rare marine dinoflagellates and the apparent conformity of the host Clinton Formation with the marginal marine Rogue Formation indicate a coastal setting. With time peat formation became more restricted and in closer proximity to channel sedimentation, both of which are possibly related to northward marine transgression and a retrograding shoreline. A relatively stable groundwater regime, together with a direct hydraulic connection between coastal peat swamps and the adjacent marine environment, are indicated. The attributes and distribution of its seams appear to reflect sedimentological factors, possibly influenced by eustatic change, while local tectonics determined the optimum site of peat accumulation.

A restricted, tectonically active sub-basin is interpreted as the likely setting for peat accumulation in the Lochiel Deposit. Here the peats were prone to periodic clastic sedimentation, especially in the south (Figure 4.18). Although proximal marine environments existed (e.g. in the nearby Pirie Basin to the northwest and the St. Vincent Basin to the south; Figure 4.1), highlighted by the presence of marine dinoflagellates within its coals, peat formation was largely shielded from marine incursion by uplifted pre-Tertiary bedrock in the south, east and west. A critical effect of such restricted conditions would be a potentially fluctuating groundwater regime subject to local tectonic, sedimentary and climatic factors. This would account for the observed repetition of depositional patterns within the sub-basin. Local tectonics, and in particular periodic movement along major structures such as the Ardrossan Fault, together with non-marine clastic sedimentation in the south appear to have exerted a strong influence over coal accumulation in the Lochiel Deposit.

## 4.6 SUMMARY

The Middle Eocene to Early Oligocene brown coals of the Bowmans and Lochiel Deposits are part of a predominantly fluvio-lacustrine succession deposited within a transgressive systems tract, in adjacent depocentres of the northern St. Vincent Basin. Coals from the Bowmans Deposit are slightly older and show evidence of their greater marine proximity. However, both sequences are overlain by marine to marginal marine sediments and their peat accumulations may have occupied broadly similar positions with respect to the marine

shoreline during the northward transgression that resulted in the diachronous and correlative Clinton Formation and Bumbunga Sand Formation.

Differences in the sedimentology of the two coal deposits reflect subtle differences in their regional setting. At Bowmans, interchannel peats accumulated on a near coastal flood plain environment, leading to seams characterised by rapid splitting and varying attributes throughout the sequence. At Lochiel, peat accumulated within a restricted and tectonically active sub-basin, where sedimentation was limited to periodic overbank deposits in the south and around the margins of the central mire. In this setting regular, lensoidal seams developed with splitting restricted to the seam peripheries.

Peat accumulation in the Bowmans Deposit appears to have been influenced by a various factors, including clastic sedimentation, local tectonics and eustatic change. The result was a relatively dynamic sedimentary setting. In the Lochiel Deposit local tectonic movement along nearby faults was the primary control of peat accumulation, resulting in broad scale repetition of depositional style through the sequence and relatively static sedimentary conditions.

# 5 PETROGRAPHIC EVALUATION AND DEFINITION OF COAL FACIES

Detailed evaluation of the Lochiel and Bowmans deposits commenced with the identification and differentiation of genetically distinct coal facies. To achieve this, assorted micropetrographic and macropetrographic data were collected, evaluated and integrated. In this chapter the petrographic characteristics used for facies differentiation are presented, gross coal attributes outlined and the Lochiel and Bowmans facies suite defined. Possible relationships to other Southern Australian brown coal varieties are also briefly considered.

## 5.1 BACKGROUND AND STRATEGY

As the first in-depth evaluation of coal in the northern St. Vincent Basin, this research project necessitated the establishment of a genetic classification scheme for its hitherto undescribed lithotypes. The process of acquiring petrographic data and developing appropriate differentiation criteria was somewhat evolutionary. Genetic and other criteria previously used for brown coal differentiation were first collated, applied and, in some cases, refined within the context of the deposits at Lochiel and Bowmans. Several new indices were developed from quantitative maceral data to help summarise their petrographic features and highlight their compositional variation. While some of the resulting criteria may be only locally applicable (i.e. pertaining only to these particular deposits), each coal type ultimately defined is thought to reflect accumulation within a unique local depositional environment.

In this study, definition of coal facies uses both macropetrographic (i.e. lithotype) and micropetrographic (i.e. maceral) data in a fully integrated manner. However, the initial collection and evaluation of these two petrographic datasets was undertaken independently, albeit on a common sample suite. Discussion in this chapter reflects these two stages, with the various parameters used to describe and differentiate the coals according to their lithotypes and maceral assemblages, and the resultant suites, reviewed separately. All differentiation criteria are then integrated and applied to identify genetically distinct coal facies within the Lochiel and Bowmans Deposits.

## 5.2 MACROPETROGRAPHIC CHARACTERISTICS

Macroscopic properties appraised in evaluation of the Lochiel and Bowmans coals include texture and wood abundance, colour, gelification, hardness, mineral content and fracturing, all common parameters in existing brown coal lithotype classifications (Francis, 1961; George, 1975, 1982; Hagemann and Hollerbach, 1980; ICCP, 1993; see also Section 2.3.1). Some properties vary with the nature of the source material, or its degree of biological degradation and reflect the local depositional environment, while others may be modified by thermal maturation and other post-depositional alteration processes.

### 5.2.1 Texture

Texture refers to the macroscopic appearance of the coal groundmass and is dependent on the nature of the source material (i.e. precursor vegetation) and its degree of preservation. In the Bowmans and Lochiel coals, texture is a very distinctive characteristic that exhibits wide variation. In this study, the distinction between groundmass tissue phytoclasts and wood fragments was set at 0.01 m, (i.e. particles greater than 0.01 m were considered as wood fragments; see Section 5.2.2).

Textural variations reflect changes in the concentration, size, shape and composition of phytoclasts. Six textural types were defined to facilitate qualitative assessment (Plate 5.1; Table 5.1). This classification is based primarily on groundmass tissue[1] abundance, with concentration increasing from absent or rare ("very earthy") to abundant ("very fibrous"). Changes also occur in groundmass tissue composition (e.g. charcoal, leaf, periderm and intact elongated plant tissue) as well as tissue morphology. While these latter features contribute to textural diversity, they do not feed directly into the textural classification. However, changes in the nature of groundmass tissue commonly occur in parallel with other macroscopic variations, including tissue abundance.

[1] Groundmass tissue refers to macroscopically discernable organic fragments ≤0.01 m in size.

Table 5.1 Groundmass texture types

| Texture Type | Groundmass Tissue Concentration | Description |
|---|---|---|
| Very earthy | Absent (to rare) | Homogenous, may show conchoidal fracture pattern. Generally dark to very dark |
| Earthy | Rare | Conchoidal fracture not apparent. Generally medium to light brown at Lochiel, but dark where transitional to very earthy. Commonly dark brown at Bowmans. |
| Weakly fibrous | Low | Some tissue discernable, but patchy/irregular occurrence |
| Moderately fibrous | Moderate | Tissue is readily apparent |
| Fibrous | High | Small platy particles aligned parallel to bedding. Generally dark. |
| Very fibrous | Abundant | Platy tissue aligned parallel to bedding. Dark at Lochiel and variable from light to dark at Bowmans. |

The most common textural types are those within the earthy to moderately fibrous range, with the moderate tissue varieties dominating at Bowmans, as opposed to earthy forms at Lochiel. Several other macroscopic properties vary with changes in texture, including colour, wood content and gelification (see Section 5.4.1.1).

### 5.2.2 Wood content

Woody inclusions (i.e. fragments greater than 0.01 m) are a readily discernible and distinguishing macro characteristic. As with groundmass tissue, wood content is a function of both source material and preservation.

The wood content of coals at Lochiel and Bowmans varies considerably. To evaluate this key characteristic, both wood type (i.e. size and morphology of fragments) and wood abundance (i.e. concentration of fragments) were assessed in a qualitative manner.

Examination of the woody fraction was primarily limited to 100 mm diameter core exposures so that some inconsistency in findings is possible. This applies particularly to the detection and assessment of larger woody particles, which tend to occur in a nuggetty, non-uniform manner. George and Mackay (1991) highlighted the importance of "megatexture" observations from pit faces for recognition of large woody material in the brown coals of the Latrobe Valley, Victoria. However, in general, identification of wood-rich and wood-poor zones from 100 mm core appears satisfactory, with reasonable lateral correlation between boreholes (see Sections 7.2.5 and 7.3.5).

### 5.2.2.1 Particle types

Three categories of wood particle were defined in order to broadly differentiate wood types and morphologies (Table 5.2; Plate 5.2). The W1 and W3 groupings effectively represent small and large fragments, respectively, while the W2 category has a distinctive particle morphology.

Table 5.2 Wood particle type categories

| Wood Type | Size Range | Morphology | Distinguishing Features |
|---|---|---|---|
| W1 | Small fragments 10 - 50 mm | Some distinctive material (i.e. round, 2 to 5 mm diameter, brittle, stems), but most have no particular form. Fragmented. | Size (commonly low gelification). |
| W2 | No limits (spans W1 and lower W3 size range) | Distinctive, elongate parallel to bedding, encased in thin red-brown or light brown periderm, largely intact, well gelified. Common size range 2-5 mm thick by 10-25 mm wide. | Distinct morphology, high gelification, generally well preserved. |
| W3 | Large particles >50 mm | Variable, generally fibrous and parallel to bedding. Fragmented. | Size, low gelification. |

Although all three wood types are widely distributed throughout the coals, wood-rich intervals typically contain a W3-dominated assemblage. The W2 wood type with its distinct morphology and suberinitic covering (common on the surface of roots; Stach *et al.*, 1982) possibly represents in situ accumulation, such as growth into the peat by roots or rhizomes (D. Christophel, pers. comm., 1996). Enhanced tissue preservation in this component, which bypasses the fragmentation and reworking associated with the surface litter stage of normally-sedimented plant material, has been highlighted by Cohen *et al.* (1987). In contrast, the W1 and W3 wood varieties are thought to reflect a combination of fragmentation of branch and stem matter with some near-surface breakdown and generally show lower gelification.

### 5.2.2.2 Abundance and orientation

Wood abundance was qualitatively assessed during macroscopic evaluation, with four general categories covering the range from very low to very high (Table 5.3). A relatively even spread in wood abundance was detected within the suite and all categories were well represented.

Table 5.3 Wood abundance categories

| Abundance | Description |
|---|---|
| Very low to absent | Appears almost wood free |
| Low | Occasional particles (probably <10% *) |
| Medium | Particles readily apparent (probably 10 - 25% *) |
| High to very high | Significant wood particles present (probably >25%*) |

Key: * Percent abundance is an indicative estimate based on visual inspection.

Wood orientation was also noted during lithotype evaluation, although limited variability was detected, with essentially flat lying particles dominant. Vertical wood fragments do exist but are uncommon.

#### 5.2.2.3 Associations

While all wood varieties may coexist, there appears to be some degree of association between particle types, with three general groupings evident.

Very woody coals typically contain large (W3) fragments, although significant amounts of smaller particles (i.e. W2 and W1) may also occur. A second association in dominated by the smaller elongate inclusions (i.e. W2) with only minor amounts of other wood types (i.e. W1 and W3). In coals displaying such characteristics the wood component shows variable concentration. The third association is common in low wood coals where small fragments occur (i.e. W1) with minor amounts of well-gelified, elongate particles (i.e. W2).

### 5.2.3 Colour

The colour of brown coal under constant moisture conditions depends on multiple factors, which are not necessarily related. They include maceral composition and, in particular, liptinite content (George, 1975, 1982; see Section 2.3.1.1) and gelification. Colour tends to lighten as liptinite content increases, while increasing gelification leads to a darkening of colour.

Under *in situ* moisture conditions, Bowmans and Lochiel coals vary from black, to light brown in colour (Plate 5.3), although over much of the coal zone only minor changes were detectable. Dark brown to brownish black types predominate. A reddish tint is commonly evident in the "medium" brown coals. More extensive differentiation would be expected with drying (George, 1975, 1982; George and Mackay, 1991).

Coals were broadly classified into three qualitative categories: dark, medium or light. Medium represented the norm, with light and dark coals reflecting a significant shift in colour. It was these latter varieties that were specifically identified during macroscopic assessment. Colour changes were generally paralleled by variations in other parameters, including texture and gelification.

### 5.2.4 Gelification

Gelification in brown coals is primarily related to *in situ* biological activity and is therefore a key indicator of depositional conditions. Gelification of both the groundmass matrix and wood particles were considered, although the former was of primary interest. While both fractions are commonly similar, significant differences in their gelification also occur.

Macroscopic assessment of groundmass gelification was limited to identification of highly gelified coal types. These are typically darker and softer than other varieties and may show a distinctive, conchoidal fracture pattern. The remaining coals are undifferentiated with respect to gelification.

Within the wood fraction, the degree of gelification is more readily apparent, varying from tough and fibrous (i.e. poorly gelified) to dark and soft (i.e. well gelified). There is a correlation between wood type and gelification, with the W2 type (and, to some extent, W1) commonly well gelified, while W3 fragments are generally poorly gelified.

More extensive assessment of gelification was undertaken using microscopic techniques (see Section 5.3.4).

### 5.2.5 Hardness

Qualitative assessment of hardness was used to identify atypical coals. In so doing deposit-specific consideration of hardness was necessary to account for the slight difference in rank between the Lochiel and Bowmans coals (see Section 4.2.5), with the latter showing slightly higher levels.

The very dark and light coals showed marked departures in hardness, being softer and harder than the norm, respectively. Both constitute relatively uncommon coal varieties. Other coal types appeared to show little variation and were undifferentiated with respect to hardness. Anomalies in hardness were generally paralleled by other macroscopic features, such as colour and gelification.

### 5.2.6 Crystalline mineral content

Detrital minerals, particularly quartz, can represent an obvious macroscopic feature. The type, grain size and distribution of minerals were described during lithotype evaluation. However, macroscopically discernable mineral enrichment which generally occurred close to the lateral limits of seams and their upper and lower boundaries, appears unrelated to coal

type. Detrital mineral was therefore of limited use for coal identification and classification. More subtle changes in the nature and abundance of detrital minerals (i.e. removed from seam boundaries) are discussed in Chapter 9.

Post-depositional crystalline mineralisation is uncommon. However, pyrite is abundant in some fractured coals.

### 5.2.7 Fracturing

Two distinctive fracture types were recognized in the Lochiel and Bowmans coals. The most pronounced fractures display a brecciated texture and occur in relatively thin horizons (generally less than 0.2 m thick). The fractured zone consists of very hard, small (1 to 30 mm) dark coal fragments. The textural fabric of coal particles could not be discerned and individual particles are largely unconsolidated. These intervals often occur within a silty matrix and are in places pyritised.

A second style of fracturing produced a relatively soft and friable, generally dark coal, with a somewhat broken appearance extending downwards for 0.5 to 2 m from the seam roof. Other lithotype characteristics such as texture, gelification and wood content were often masked in such zones.

Fractured coals are relatively rare, but where present can be very clearly identified. The remainder of the sequence was undifferentiated with respect to fracturing and consisted of essentially massive coals. In contrast to other macroscopic characteristics, fracturing typically reflects post-depositional modification.

## 5.3 MICROPETROGRAPHIC CHARACTERISTICS

### 5.3.1 Introduction

Quantitative maceral data facilitated the development of assorted indices to succinctly summarise micropetrographic characteristics and assist coal discrimination. Some follow concepts previously employed in genetic classifications, or palaeoenvironmental studies, (ICCP, 1971; Diessel, 1986, 1992; Kalkreuth and Leckie, 1989; Kalkreuth *et al.*, 1991; Marchioni and Kalkreuth, 1991; Mavridou *et al.*, 2003; Silva and Kalkreuth, 2005), while others were specifically generated during this research. Within this study, maceral indices are employed primarily to assist coal differentiation by highlighting changes in petrographic character, as advocated by Crosdale (2004). They are not used as the basis for qualitative

classification of coal type, nor as a definitive tool for the evaluation of depositional environment.

The principal maceral features used herein include gross composition, cell preservation, gelification and the nature of the liptinite assemblage (Table 5.4). Each of these parameters is sensitive to local palaeoenvironmental conditions and, in particular, precursor vegetation and biomechanical factors.

Table 5.4 Maceral parameters

| Parameter | Indicative Of |
|---|---|
| Maceral group abundance | Nature of source material, extent of biomechanical degradation, extent of oxidation/alteration |
| Cell preservation | Extent of biomechanical degradation, nature of source material |
| Gelification | Water depth, biochemical conditions |
| Liptinite assemblage | Nature of source material |

### 5.3.2 Maceral group abundance

Maceral group abundance (i.e. relative proportions of vitrinite, liptinite and inertinite) provides a simple means of gross coal differentiation and identifies major changes in coal type. The Lochiel and Bowmans coals are dominated by vitrinite, with low to moderate liptinite and very low inertinite. Consequently, relatively subtle changes in the concentrations of liptinite and especially inertinite are considered significant; and, in general, atypical maceral group concentrations allow ready differentiation of coal facies.

Frequency distributions and ternary plots of maceral occurrence at Lochiel and Bowmans are presented in Figures 5.1 and 5.2, and the characteristics of their respective maceral groups are reviewed below.

#### 5.3.2.1 Vitrinite

Vitrinite is the principal maceral in the Lochiel and Bowmans coals. Its precursors (viz. woody tissue comprising chiefly lignin and cellulose) represent the dominant source material in most coal-forming settings, but are also the most susceptible to decay and alteration (Taylor *et al.*, 1998). Vitrinite abundance depends on several factors including initial concentration, susceptibility to bacterial and fungal breakdown (i.e. vitrinite depletion with respect to the more resistant liptinite and inertinite) and the extent of vitrinite alteration to inertinite.

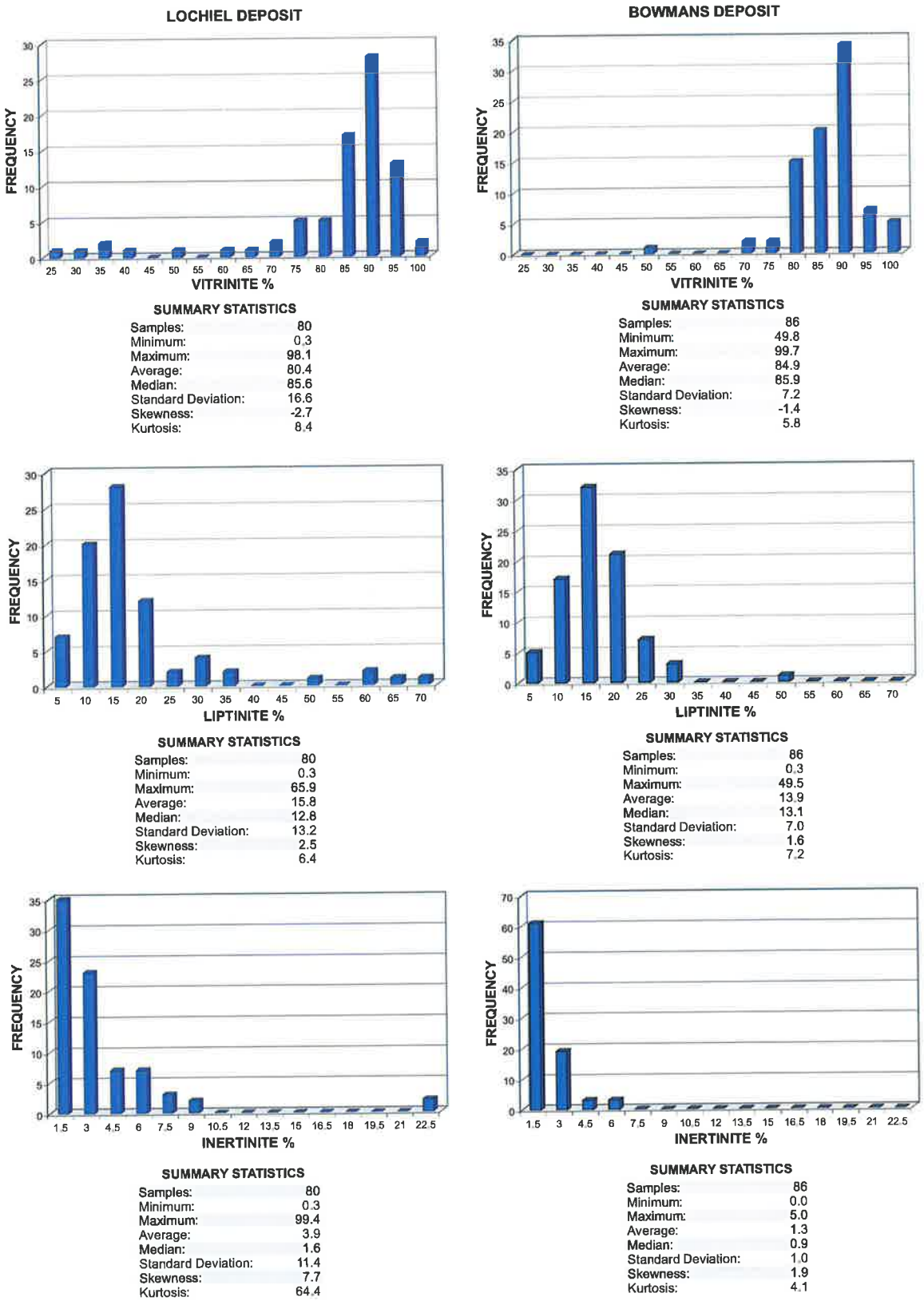



Figure 5.1 Frequency distributions of maceral group content

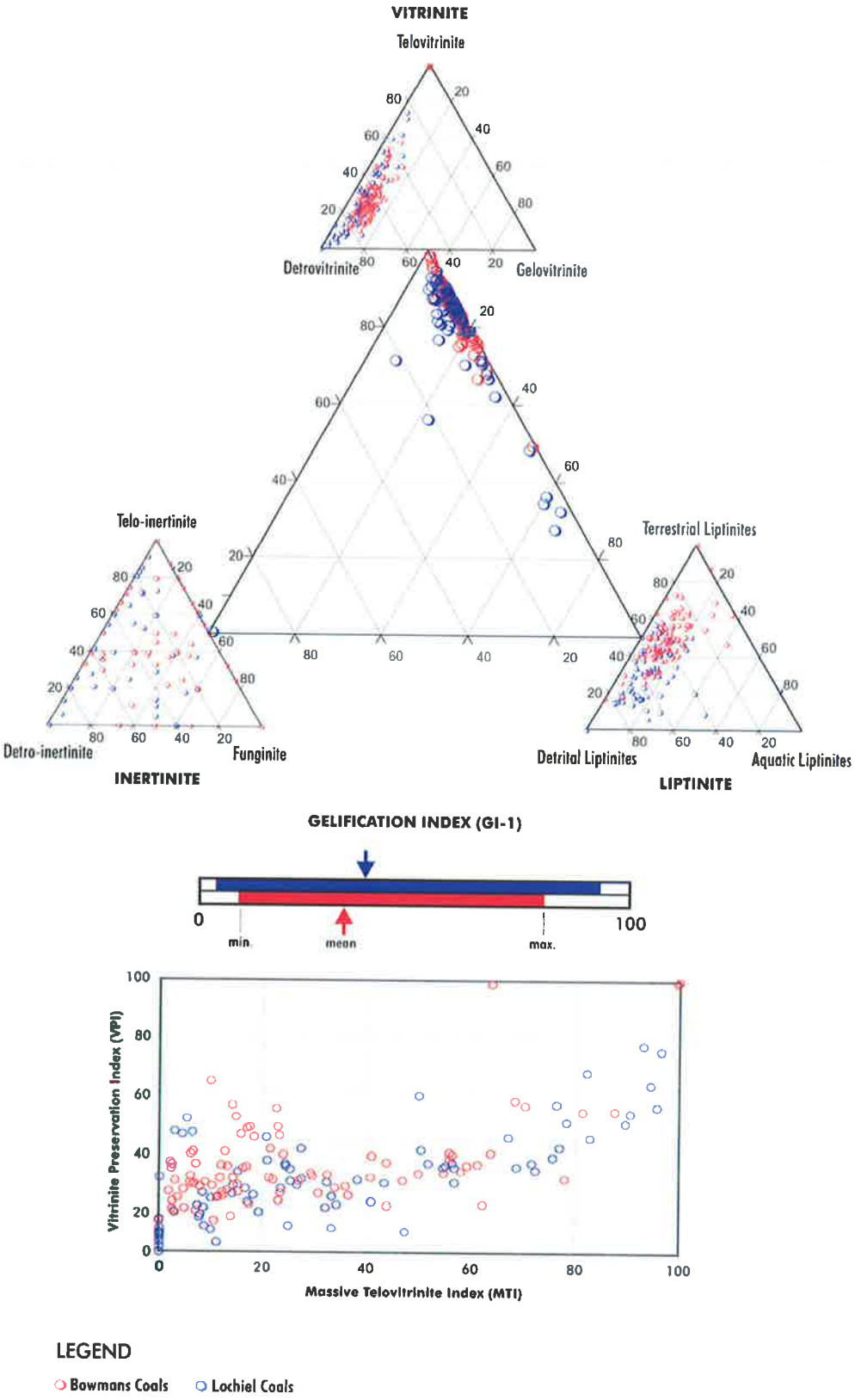



Figure 5.2 Maceral characteristics represented on ternary diagrams, and key maceral indices

Vitrinite abundance in these brown coals ranges from 30 to 100%, but is typically between 85 and 95% (Figures 5.1 and 5.2), averaging approximately 81% at Lochiel and 85% at Bowmans. The lower level in the Lochiel coals reflects their broader spread of coal characteristics and the presence of some reduced vitrinite varieties. Based on the observed maceral distributions, vitrinite contents of <80% appear anomalously low, possibly indicating preferential depletion of vitrinite during peat accumulation.

In general, gross vitrinite group abundance appears to have limited application for coal differentiation. However, the nature of constituent vitrinite macerals varies significantly, particularly with regard to cell preservation and gelification, and potentially provides the basis for further differentiation (see Sections 5.3.3 and 5.3.4).

#### 5.3.2.2 Liptinite

Liptinite macerals form from the fatty and waxy parts of plants (e.g. cuticle, resin, spore exines) and are resistant to both mechanical and bacterial breakdown (Taylor *et al.*, 1998). Their abundance is dependent on the nature of the source material and the extent of relative enrichment, which both vary with local palaeoenvironmental conditions. Furthermore, several liptinites can be directly related to particular plant components, warranting specific evaluation of the assemblage for coal differentiation (see Section 5.3.5).

Liptinite content generally varies inversely with vitrinite and shows an extensive spread (i.e. <1 to 66%), with Lochiel coals exhibiting the highest concentrations. Typical abundances are in the order of 10 to 20%, (Figures 5.1 and 5.2), higher values being anomalous for these deposits. Unusually low liptinite abundance is harder to define, but is probably less than 5%. Very high liptinite content provides a ready means of micropetrographic facies definition.

#### 5.3.2.3 Inertinite

Inertinite group macerals are resistant constituents and their abundance may reflect selective enrichment, susceptibility of the hinterland to forest fires, or the contribution of fungal remains (i.e. funginite).

Inertinite is relatively uncommon in the Lochiel and Bowmans coals, with levels typically less than 3% (Figures 5.1 and 5.2). However, two discrete populations with elevated inertinite contents are evident at Lochiel. In the most widespread group, concentrations range from 3 to 9%, while in a less common variety inertinite content is very significantly elevated (i.e. >20% and, in one case, as high as 90%). High inertinite content facilitates ready micropetrographic facies differentiation.

#### 5.3.2.4 Maceral group summary

Maceral group abundances provide some useful facies-assessment criteria, with unusual varieties showing very high liptinite and inertinite likely to be defined on gross maceral abundance alone. However, over the majority of the vitrinite-dominated coal suite present in the Lochiel and Bowmans Deposits, maceral group composition in isolation is unsuited as a primary means of discrimination.

### 5.3.3 Tissue preservation

Immediately prior to, or at the time of their incorporation into peat, macerals exist as fragments of plant tissue (i.e. phytoclasts). However, the size and degree of phytoclast preservation within coals varies considerably in line with the level of biomechanical activity during peat accumulation, the composition of source material and the means by which vegetable matter is incorporated into the peat (Stach *et al.*, 1982; Cohen *et al.*, 1987; Holdgate *et al.*, 1995; Holdgate *et al.*, 2000; Moore and Shearer, 2002). These factors are likely to be closely dependent on local depositional conditions. The wide range in phytoclast preservation evident in the coals at Lochiel and Bowmans suggests a parameter highly suitable for coal identification and classification.

Tissue preservation was assessed mainly within the vitrinite fraction, due to the dominance of this maceral group. However, sufficient liptinite also exists to permit meaningful evaluation, thereby providing a measure of the relative degradation within this more resistant maceral fraction.

The relative concentration of individual macerals and some locally defined sub-macerals were applied to assess tissue preservation. In particular, the concentration of intact *versus* fragmented material and the relative abundance of large and small tissue phytoclasts were considered. To concisely summarise these data, three indices were developed following the principal of tissue preservation index (TPI; Diessel 1986, 1992):

- Vitrinite Preservation Index (VPI)
- Liptinite Preservation Index (LPI)
- Massive Telovitrinite Index (MTI)

VPI and MTI are based on the vitrinite component, while LPI evaluates the liptinite fraction.

### 5.3.3.1 Vitrinite preservation index

The VPI measures the abundance of intact phytoclasts of vitrinite (woody tissue) relative to fragmented vitrinite and provides a measure of the extent of its mechanical and biological reworking (Plate 5.4):

VPI = [ telovitrinite / (telovitrinite + detrovitrinite) ] x 100

Index values range from 0 to 100, with increasing tissue preservation indicated by a higher index level. Values in the Lochiel Deposit show a wide distribution (VPI mostly 0 to 55, mean ~28; Figure 5.3). However, at Bowmans the values fall predominantly in the range 15 to 40 (mean ~32). The very low and high VPI values measured at Lochiel are not repeated in the Bowmans coals, reflecting the greater facies and palaeoenvironmental diversity of the former deposit.

### 5.3.3.2 Liptinite preservation index

The LPI is a measure of the relative abundances of primary (i.e. intact and directly sourced from plant constituents) and fragmented liptinite (Plate 5.5). Like VPI, it monitors the extent of biological and mechanical breakdown of phytoclasts (± phyterals) in the peat mire. It is defined as follows:

LPI = [ primary liptinite / (primary liptinite + fragmented liptinite) ] x 100

*Where:*

*Primary liptinite = sporinite + cutinite + resinite + suberinite + alginite*

*Fragmented liptinite = liptodetrinite*

Index values range from 0 to 100, and increase with preservation. At Lochiel, LPI typically ranges from 20 to 70 (mean ~48) and shows a relatively even spread of values over the coal-bearing interval (Figure 5.3). At Bowmans, LPI values are both higher and more uniform (typical range = 45-80, mean ~60), confirming the lower coal diversity evident in the VPI distribution. Better preservation of liptinite, relative to vitrinite, is also apparent in each deposit (Figure 5.3).

Qualitative evaluation of liptinite particle size confirmed a broad inverse relationship with LPI.

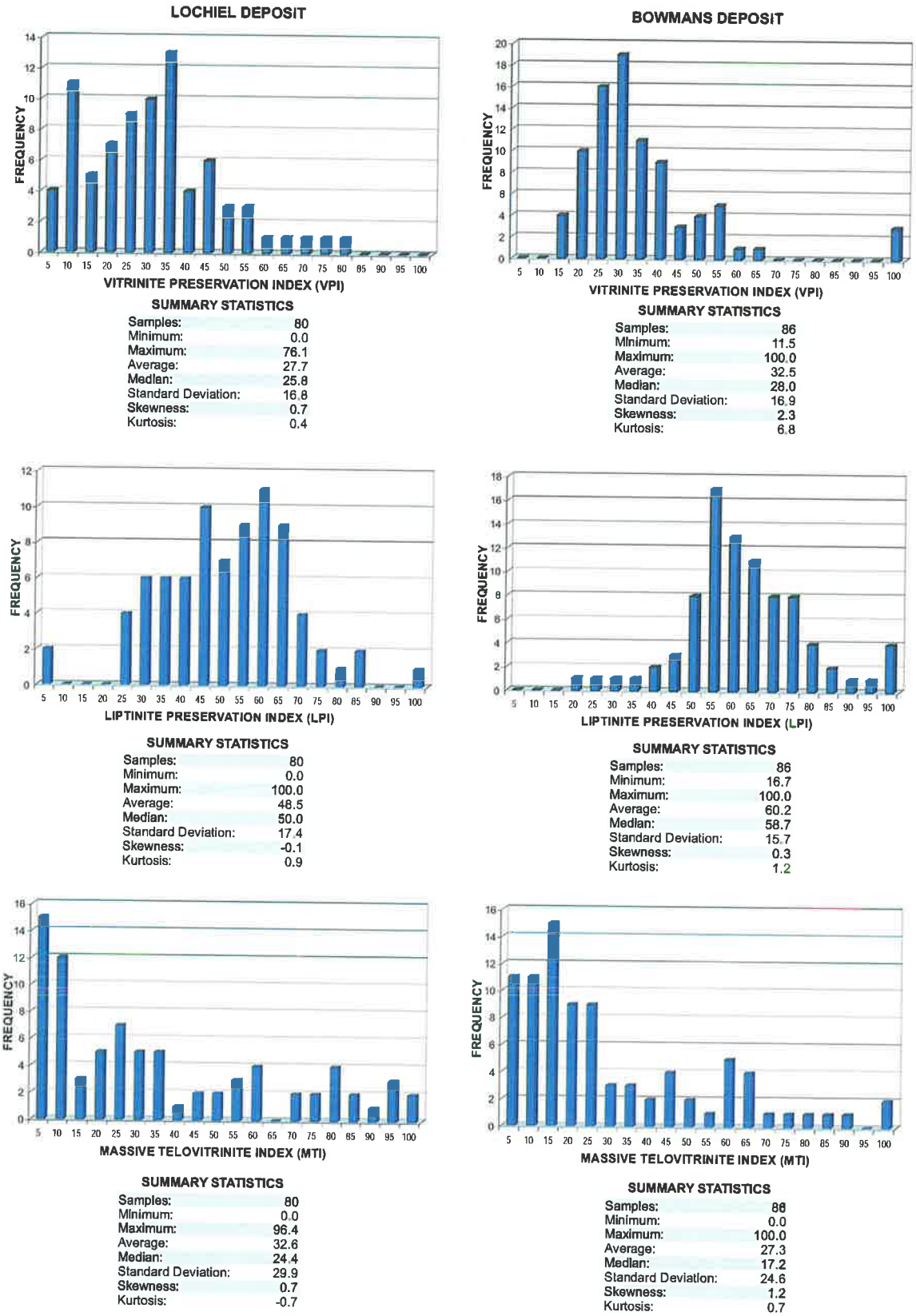



Figure 5.3 Frequency distributions of tissue preservation indices

### 5.3.3.3 Massive telovitrinite index

The MTI assesses the preservation of cellular vitrinite (i.e. telovitrinite) and, in particular, the relative abundance of very large phytoclasts relative to total telovitrinite, including the smaller cell remnants occurring within a detrital groundmass (Plate 5.4). The MTI provides a measure of source material and its degradation, and aims to differentiate between coals with similar total telovitrinite contents, but with contrasting particle size distributions (i.e. fine groundmass fragments *versus* larger particles). These components are analogous to the groundmass tissue and woody fractions in lithotype evaluation.

MTI is defined as follows:

MTI = (massive telovitrinite / total telovitrinite) x 100

*Where:*

*Massive telovitrinite = Large telovitrinite phytoclasts, exceeding approximately 250 μm and commonly occurring as single grains devoid of detrovitrinite*

The index uses the four telovitrinite macerals to calculate total telovitrinite, (i.e. textinite, texto-ulminite, eu-ulminite and desmocollinite) in conjunction with a telovitrinite size sub-classification developed specifically for this research (Appendix C1; Plate 5.4).

Index values range from 0 to 100, increasing with the concentration of large telovitrinite phytoclasts (and wood). MTI values span the full range at both Lochiel and Bowmans (Figure 5.3), but as with other tissue indices, the distribution is more regular and coal diversity least in the Bowmans Deposit. Here MTI is more strongly skewed to lower values (<30). At Lochiel MTI is more erratic with slightly increased frequency in the 0 to 30 range. In general, the broad MTI range suggests a wide variation in massive telovitrinite (and wood content) for both deposits, with an increased tendency for their occurrence in the Lochiel coals indicated by higher average and median MTI (Figure 5.3).

### 5.3.3.4 Tissue preservation summary

Tissue preservation indices succinctly summarise the characteristic features of vitrinite (and liptinite) in these brown coals. In particular, they provide a micropetrographic means of assessing inter- and intra-deposit variation in key lithotype characteristics such as texture and wood content (i.e. through VPI and MTI, respectively). Importantly, wide variations in cell preservation facilitate further differentiation of the high-vitrinite coals. Identification of several coal facies appears feasible by using VPI and LPI to monitor overall tissue preservation. In addition, information on tissue phytoclast size (i.e. MTI) makes possible the

clear sub-division of the telovitrinite-rich coals into those with predominantly massive tissue and those dominated by groundmass tissue. Application of cell preservation indices is discussed further in 5.4.2 where key micropetrographic data are integrated and the correlation to lithotype criteria reviewed in Section 5.4.3.

### 5.3.4 Gelification

During gelification, the organic constituents of a peat swell, occluding cell lumens and filling the voids between discrete phytoclasts. The result is a more coherent peat groundmass (Stach *et al.*, 1982; Plate 5.6). Initial gelification is mediated by the enzymes of fungi (aerobes) and bacteria (both aerobic and anaerobic). Such *biochemical* gelification is promoted in subaqueous anaerobic environments and so its extent is closely related to water depth (Stach *et al.*, 1982; Diessel, 1992). Subsequent *geochemical* gelification is likely to have been limited in these northern St. Vincent Basin coals because of their shallow burial. Differences in gelification within the individual deposits, where rank is essentially constant, are therefore likely to be due to variations in depositional factors such as water depth, Eh and pH.

A gelification index may be used to assess the extent of this type of alteration. Modelled on those of George (1982) and Diessel (1986, 1992), two indices (GI-1 and GI-2) were developed based on the relative abundances of vitrinite macerals. GI-1 assesses the gelification of detrovitrinite, whereas GI-2 considers both the detrovitrinite and telovitrinite sub-groups. The former targets constituents that have been through the surface litter stage of the peat and is probably the best indicator of local depositional conditions. Gelification of telovitrinite macerals within Lochiel and Bowmans coals appears less consistent, possibly in line with differing precursors (e.g. subaerial root matter *versus* wood particle; see Section 2.1.1) and the hypautochthonous[2] nature of some woody material. This contrasts with the findings of George and Mackay (1991) who noted that gelification in Latrobe Valley coals was generally more advanced in woody tissue than in the detrital groundmass.

Gelification indices were defined as follows:

GI-1 = 1 x [Attrinite / Detrovitrinite] + 50 x [ Densinite / Detrovitrinite] + 100 x [Desmocollinite / Detrovitrinite]

GI-2 = 1 x [(Attrinite + Textinite + Texto-ulminite) / (Detrovitrinite + Telovitrinite)] + 50 x [(Densinite + Eu-ulminite) / (Detrovitrinite + Telovitrinite)] + 100 x [(Desmocollinite + Telocollinite) / (Detrovitrinite + Telovitrinite)]

[2] Hypautochthonous denotes shifting and redeposition of vegetable matter within peatswamps (Diessel, 1992)

In both deposits GI-1 covers the full possible range (i.e. 1 to 100) with values between 10 and 60 most common (Figure 5.4). However, at Lochiel the most extreme varieties (i.e. highly gelified and poorly gelified coals) are better represented. In each case, the distribution of GI-2 values parallels that of GI-1, although the median values are lower (Figure 5.4).

The diversity of gelification evident in each deposit highlights the potential of this parameter for discriminating between different coal facies.

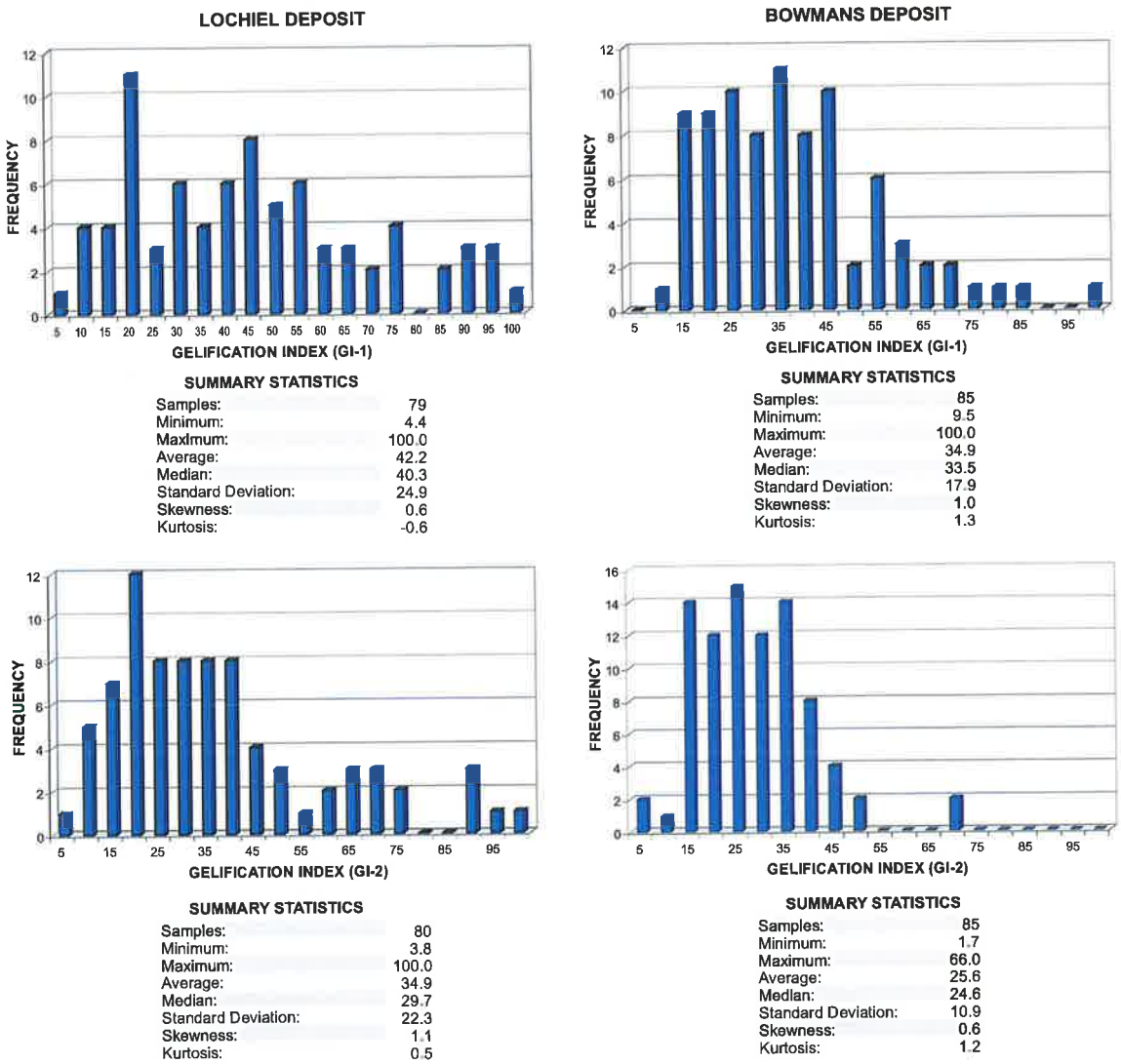



Figure 5.4 Frequency distributions of gelification indices

### 5.3.5 Liptinite assemblage

Unlike other maceral groups, many liptinite macerals can be directly related to their botanical precursor (e.g. cuticle, spore, resin, suberin), allowing assessment of the particular environments that favour their accumulation and preservation. The importance of the liptinite fraction for coal differentiation has been highlighted by many workers (e.g. Francis, 1961; Ward, 1984; Kalkreuth *et al.*, 1991).

The liptinite assemblage was used to derive two indices as follows:

- Liptinite environmental index (LEI)
- Liptinite alteration index (LAI)

The former considers the relative abundance of various primary liptinites, while the latter focuses on the ratio of secondary to primary liptinites.

### 5.3.5.1 Liptinite environmental index

The LEI develops the concept of liptinite-based palaeoenvironmental differentiation proposed by Kalkreuth *et al.* (1991) and, like Diessel (1982), utilises locally defined sub-macerals and maceral associations. Liptinite macerals were classified and weighted according to their source and likely depositional setting (Plate 5.7). Terrestrial and aquatic groups were defined to reflect diverse groundwater conditions, interpreted as forest swamps and treeless open water settings, respectively. While such an approach is a simplification of complex processes involving transportation, accumulation and preservation (as noted by Wust *et al.*, 2001; Scott, 2002), some clearly defined liptinite assemblages were recognised. Herein, LEI is used in conjunction with other parameters to identify genetically distinct coal types, rather than as a prescriptive tool for determination of depositional environment.

LEI was defined as follows:

$$\text{LEI} = 1 \times [\text{terrestrial liptinite} / \text{total liptinite}] + 50 \times [\text{fragmented liptinite} / \text{total liptinite}] + 100 \times [\text{aquatic liptinite} / \text{total liptinite}]$$

*Where:*

*Terrestrial liptinites = resinite + suberinite + cutinite "L"*

*Fragmented liptinites = liptodetrinite*

*Aquatic liptinites = alginite + [Σ cutinite - cutinite"L"] + sporinite*

*(Note: Cutinite "L" is a locally defined sub-maceral showing a distinct morphology: see Section 5.3.6, Appendix C1)*

The terrestrial liptinite grouping includes components most likely sourced from woody, forest flora growing in periodically inundated mire environments. Resinite (from resins, commonly in woody tissue), suberinite (from corkified cell walls) and cutinite "L", from leaves and stems, were identified as the most probable liptinite components to be diagnostic of this setting. Cutinite "L" is closely associated with both large telovitrinite phytoclasts and large

woody fragments. It is unusually thick possibly reflecting relatively dry conditions (A. Rowett, pers. comm., 1992; Plate 5.8) and may represent a leaf midrib.

The aquatic liptinite group includes components likely to occur in environments of permanent standing water devoid of forest vegetation, or those showing preferential preservation in such settings, with alginite, cutinite other than type "L" and sporinite specifically identified. Alginite, diagnostic of this assemblage, is characteristic of lacustrine settings (Diessel, 1992; Taylor *et al.*, 1998). Preservation of cutinite, often as very thin varieties (i.e. exclusive of type "L"), is interpreted to be largely restricted to wet, stable settings, with limited mechanical and aerobic activity (Plate 5.8). Sporinite, while showing allochthonous tendencies, is commonly enriched in aquatic environments (Teichmuller, 1989; Taylor *et al.*, 1998).

The LEI ranges from 1 to100, increasing from low values in terrestrial settings to high values in aquatic environments. The Lochiel and Bowmans coals have markedly different LEI distributions, the former being bimodal and the latter unimodal (Figure 5.5), while the interval of elevated frequency varies from 30 to 55 in Lochiel coals compared to 20 to 40 in Bowmans varieties. Both terrestrial and aquatic assemblages are clearly apparent at Lochiel, while at Bowmans the liptinites are predominantly terrestrial.

#### 5.3.5.2 Liptinite alteration index

The LAI measures the ratio of secondary to primary liptinites (Plate 5.9) and aims to assess the extent of biological degradation on the liptinite fraction.

LAI is defined as follows:

LAI = [secondary liptinite / primary liptinite] x 100

*Where:*

*Primary liptinite = resinite + sporinite + suberinite + cutinite + liptodetrinite + alginite*

*Secondary liptinite = bituminite + fluorinite*

Primary liptinites are those for which the original botanical precursor can be clearly identified; and also liptodetrinite which, although fragmented, is not a specific degradation product. Secondary liptinites do not display a distinct morphology (Diessel and Smyth, 1995) and can not be related to specific organic constituents. Bituminite is a product of the bacterial decay of structured plant and algal tissue in both subaqueous and aerobic environments (Teichmuller, 1989; Crosdale, 1993; Taylor *et al.*, 1998). Its close association with terrestrial liptinite rich facies in the Lochiel/Bowmans coals suggests that here it is most likely to be

sourced from vascular plant material. Fluorinite precursors include essential oils, possibly from lipid inclusions in certain leaves (Teichmuller, 1989; Taylor *et al.*, 1998) and in this study are restricted to a facies showing intense and atypical gelification.

Secondary liptinites are very rare in the Bowmans coals (LAI <13) and are of moderate to low abundance in those at Lochiel (LAI <36; Figure 5.5). The broader range (and increased diversity) at Lochiel parallels the pattern in several other maceral parameters.

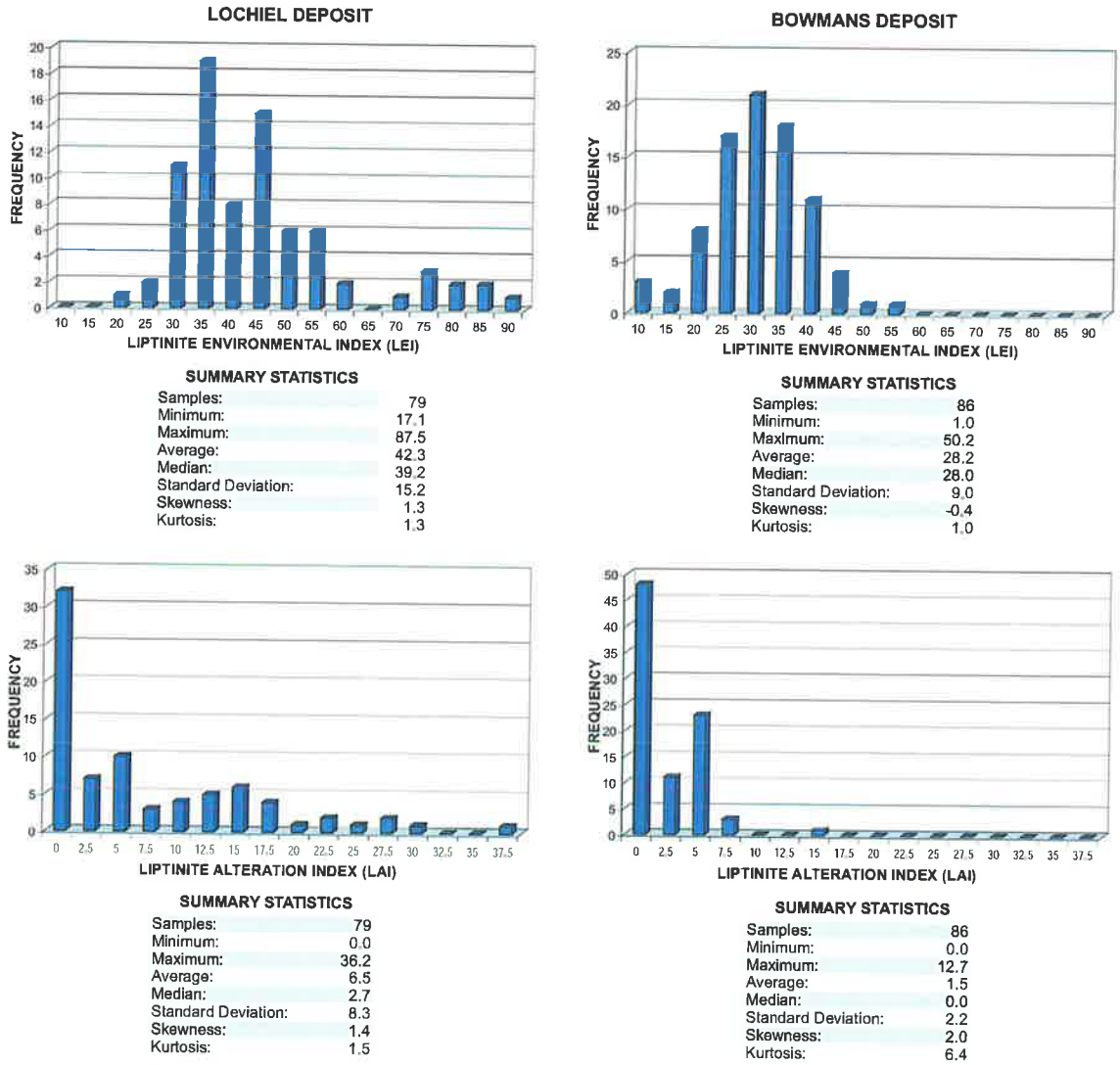



Figure 5.5 Frequency distributions of liptinite composition indices

### 5.3.5.3 Liptinite assemblage summary

Assessment of the liptinite assemblage by LEI and LAI enables clear differentiation between terrestrial and aquatic-dominated facies. In addition, while limited secondary liptinites exist, anomalously degraded coal types can be readily identified.

### 5.3.6 Other parameters

During micropetrographic evaluation some distinctive maceral attributes were detected. Where consistent identification was possible, they were qualitatively and in some cases quantitatively assessed. In particular, local sub-macerals and microtextures were defined to identify distinct maceral morphologies and occurrences, respectively (Plates 5.8, 5.10 – 5.13; Appendix C1). These definitions are specific to the Lochiel and Bowmans coals and follow the approach adopted by Diessel (1982, 1992) for palaeoenvironmental and facies interpretation.

The nature and forms of telovitrinite were classified to differentiate large phytoclasts consisting entirely of telovitrinite from smaller forms surrounded by groundmass (Plate 5.4), thereby providing the basis for the new MTI parameter. Furthermore, within the large phytoclasts two sub-maceral qualifiers were established to account for differing degrees of gelification (i.e. low and high, defined as types "D" and "F", respectively; see Appendix C1). Within the groundmass telovitrinite particle size, morphology, extent of degradation and gelification were applied to define four possible telovitrinite types (Appendix C1). Types "B" and "D" are small phytoclasts (< 50 μm) showing a high degree of cell wall breakdown and pitting, while "A" and "E" designate elongate phytoclasts (< 250 μm) in length. Gelification is low in the former and high in the latter.

Within the liptinite fraction, a number of cutinite, resinite and suberinite types were defined based on distinctive and/or commonly occurring morphologies (Plates 5.8, 5.10 and 5.11, respectively; Appendix C1). Other features recorded include a peculiar form of *in situ* tissue degradation showing cell-wall breakdown and enrichment of fine liptinite (Plate 5.12); and a distinctive microtexture consisting of well sorted corpogelinites, with some funginite and inertodetrinite (Plate 5.13).

Local sub-macerals and textures in isolation do not lead to the differentiation of unique coal facies. However, some were used in developing tissue preservation and liptinite environment indices and, together with other micropetrographic data, they contribute to the overall process of evaluation and classification, especially at Bowmans where coal diversity is limited.

## 5.4 DEFINITION OF COAL FACIES

A combination of qualitative lithotype assessment and quantitative maceral data proved effective in recognising genetically distinct coal facies in the Lochiel and Bowmans Deposits of the northern St. Vincent Basin.

### 5.4.1 Coal lithotypes

#### 5.4.1.1 Integration and application of macroscopic criteria

The macroscopic characteristics of the Lochiel and Bowmans coals display considerable diversity. A suite of lithotypes was defined by integration of the macroscopic features summarised in Table 5.5. While in isolation each feature generally has limited significance, most are interrelated to some extent, allowing a clearer differentiation of lithotype when all properties are considered.

Table 5.5 Summary of lithotype criteria

| Parameter | Characteristics |
|---|---|
| Texture | Broad range from very earthy/homogenous to very fibrous. Six textural types defined. |
| Wood content | Broad range in morphology, size and abundance. Three wood particle types defined using size and morphology and fourfold abundance classification from very low to very high. |
| Colour | Significant variation from pale to dark. Differentiation limited to identification of coals lighter and darker than the deposit norm. |
| Gelification | Restricted macroscopic resolution. Differentiation limited to well gelified coals. |
| Hardness | Limited macroscopic resolution. Differentiation limited to coals outside the normal deposit range (i.e. softer and harder). |
| Mineral matter | Obvious macroscopic feature, but appears unrelated to other macroscopic characteristics. |
| Fracturing | Where present is very distinctive. Two types of fractured coal identified. |

The size and concentration of groundmass tissue (and resulting groundmass texture) together with wood content, were considered the most appropriate means for defining primary lithotypes. These parameters are used, either exclusively or extensively, in many lithotype classification schemes (Francis, 1961; Hagemann and Hollerbach, 1980; Mukhopadhyay, 1986; ICCP, 1993). Moreover, these features vary widely and can be readily and consistently assessed in slim bore cores, under *in situ* moisture conditions. Texture and wood content also encapsulate more specific information on the precursor vegetation and its degree of preservation, and hence are likely to be good indicators of local palaeoenvironmental conditions.

Lithotype differentiation based on colour, which along with texture is commonly used for coal classification, does not qualify as a primary classifier as this property is considered independent of facies (Hagemann and Hollerbach, 1980; Mackay *et al.*, 1985; Winkler, 1986; Hagemann and Wolf, 1987; George and Mackay, 1991). Nevertheless, colour proved useful for identification of an uncommon, but distinctive, pale coal. Other properties such as gelification and fracturing may also be diagnostic for less common coal types, including a dark, highly gelified member and a fractured variety, respectively. However, with the exception of the latter (probably reflecting post-depositional modification), coal differentiation is supported by multiple macroscopic features. Hardness and mineral matter provided a more complete description of coal characteristics, but were not used to specifically define lithotypes.

### 5.4.1.2 Lithotype definition

Nine coal lithotypes (designated L1 to L9) were identified by evaluation of their macroscopic characteristics (Table 5.6). These diagnostic characteristics vary somewhat between the two deposits, with definition of standard criteria being biased slightly toward Lochiel where coal diversity and data availability are greatest. Indeed, the full coal suite is recognised only in the Lochiel Deposit (refer Chapters 6 and 7).

Table 5.6 Coal lithotypes defined from macroscopic evaluation

| | Gm. Tissue Concentration | Gm. Tissue Size | Gm. Texture | Wood Content | Colour | Gelif-ication | Fracturing |
|---|---|---|---|---|---|---|---|
| L1 | **Absent / rare** | - | Earthy | Absent | **Pale brown to yellow** | - | - |
| L2 | **Low & erratic** | Variable | Earthy | Absent / very low | Medium to light brown | - | - |
| L3 | **High** | **Medium & elongate** | Earthy | **W2-rich** | Medium to dark brown | Moderate to high | - |
| L4 | **High to very high** | **Large** | Earthy | **Abundant W3 (with W2 & W1)** | Light to medium brown | - | - |
| L5 | **Moderate to high** | **Small** | Moderately fibrous | Absent | Dark brown to black | Moderate to high | - |
| L6 | **High to very high** | **Small** | **Very fibrous** | Absent | Dark brown to black | Moderate to high | - |
| L7 | **Absent / rare** | - | **Very earthy (homogenous)** | Absent | **Dark brown to black** | **High** | - |
| L8 | Variable | Variable | Variable | Variable | Variable, but often light | Variable | **Friable** |
| L9 | Unclear | Unclear | Unclear | Unclear | Unclear | Unclear | **Fragmented** |

Key: Critical identification parameters are highlighted in bold font
Abbreviations: Gm. = groundmass

The L1 and L2 lithotypes are characterised by their very low groundmass tissue contents and the absence of wood, with the two varieties being distinguished by their colour. The former is pale brown to yellow (much lighter than the normal deposit range), has greater hardness and is commonly, but not exclusively, found in thin bands. L2 is medium to light brown in colour.

The L3 and L4 lithotypes are distinguished by a high to very high tissue content in the form of wood fragments. The L3 lithotype is dominated by elongate, highly gelified wood (i.e. W2), while the L4 lithotype usually contains an abundance of large fibrous W3 fragments, with variable but lesser amounts of the W2 and W1 wood types. Colour in these woody lithotypes can vary significantly and spans the range from light brown to dark brown.

High groundmass tissue contents, but an absence of wood inclusions characterise the L5 and L6 lithotypes. Tissue occurs as small fragments within the coal groundmass, resulting in a fibrous texture. Hard, platy charcoal fragments commonly occur within the more fibrous member (i.e. L6). Both coal types range from dark brown to black and are somewhat darker than the earthy coals (i.e. L1 to L4).

The L7 lithotype is a dark, highly gelified coal. Tissue content is low to very low. At *in situ* moisture the coal is relatively soft and may show a conchoidal fracture pattern. This coal type is uncommon and tends to occur in relatively thin bands, although intervals up to 1 m can be locally developed.

Fracture patterns distinguish the L8 and L9 coal types and both are thought to reflect the alteration of primary lithotypes (i.e. L1 to L7). The L8 variety comprises fractured and friable intervals in which the original coal texture and other macroscopic characteristics may still be recognised. However, L9 consists of small, hard coal particles within thin highly fragmented zones (0.05 to 0.25 m thick) in which the original coal characteristics are obscured. Both coals are relatively uncommon and are restricted to the Lochiel Deposit.

### 5.4.2 Micropetrographically-defined coal types

#### 5.4.2.1 Integration and application of maceral parameters

Maceral assemblages and their petrographic characteristics vary considerably in both deposits, although the Lochiel coals display somewhat greater diversity. Maceral group abundance, tissue preservation, liptinite assemblage and gelification appear to be key discriminators. The maceral parameters selected for coal differentiation, and the extent of their variation, are summarised in Table 5.7.

Table 5.7 Summary of maceral parameters

| Parameter | Characteristics |
|---|---|
| Maceral abundance | Broad range in abundance of vitrinite and liptinite. Anomalously high (and low) liptinite and elevated inertinite contents apparent. |
| Tissue preservation | Broad range in vitrinite and liptinite cell preservation. Telovitrinite rich and telovitrinite poor forms observed. Variation from groundmass-dominated to large phytoclast-dominated forms. |
| Gelification | Extensive variation, especially at Lochiel. Poorly, moderately and well-gelified coals recognised. |
| Liptinite assemblage | Wide variation with terrestrial, aquatic and mixed assemblages interpreted. A highly degraded coal type also occurs. |
| Other parameters | Several distinct sub-macerals and microtextures identified. |

Micropetrographic data were integrated and applied in a similar manner to the consideration of macropetrographic characteristics (see Section 5.4.1). Although some types could be unambiguously recognised using a single maceral parameter, the basis for classification and differentiation was in all cases strengthened by use of the total data set.

### 5.4.2.2 Micropetrographic coal definition

Seven micropetrographically defined coals, designated M1 to M7 were recognised (Table 5.8). While the full suite is present in the Lochiel Deposit, only four types were recognised at Bowmans.

Table 5.8 Coal types identified from micropetrographic evaluation

| | Maceral Content | Tissue Preservation | Tissue Occurrence | Gelification | Liptinite Assemblage | Liptinite Alteration | Deposit |
|---|---|---|---|---|---|---|---|
| M1 | **Abundant liptinite** | Very poor | Groundmass | Low | Terrestrial | **High** | L & B |
| M2 | **High liptinite** | **Poor** | Groundmass | Low | **Terrestrial** | Low | L & B |
| M3 | High vitrinite | **Excellent** | **Massive** | Low | Terrestrial | Low | L & B |
| M4 | High vitrinite | **Good** | **Groundmass** | Moderate | **Mixed** | Low | L & B |
| M5 | **Moderate inertinite Low liptinite** | **Excellent** | **Groundmass** | High | **Aquatic** | Low | L |
| M6 | High vitrinite | Poor | Groundmass | **Very high** | **Aquatic** | Moderate | L |
| M7 | **Abundant inertinite** | Variable | Variable | Variable | Variable | Low | L |

Key: Critical parameters for identification are highlighted in bold font
Abbreviations: L = Lochiel, B = Bowmans

M1 is a distinctive coal in which liptinite is very abundant and the relative concentration of degraded liptinites (expressed by LAI) is significantly higher than in other coals. Cell preservation is very poor. The characteristics of M2 are similar to those of M1, although its liptinite content is lower and liptinite alteration significantly reduced. Lower liptinite contents and the presence of abundant, large telovitrinite phytoclasts (i.e. high MTI) characterise M3. However, this type has a liptinite assemblage and a degree of vitrinite gelification that are similar to those in M2 and M1.

Excellent tissue preservation combined with the dominance of groundmass telovitrinite (i.e. high VPI and low MTI) are distinguishing features of the M4 and M5 coals. In addition, their vitrinites are moderately to highly gelified. However, some differences exist, particularly in the inertinite content, which is highest in M5; and in the liptinite assemblage that is aquatic dominated in M5, compared to a mixed composition in M4. Similarities between these coals suggest they may reflect peat accumulation in broadly similar depositional settings.

M6 is distinguished by the very high gelification of its vitrinite. In addition, an aquatic liptinite assemblage, elevated liptinite alteration and low tissue content contribute to its differentiation. It has some similarities to M5.

M7 is an inertinite-dominated coal that differs significantly from all other types. The key inertinite maceral is macrinite, suggesting oxidation of the coal after accumulation, rather than modification of its constituents prior to incorporation within the peat. This type is therefore considered an altered coal, which could potentially form from any of the primary varieties. High inertinite is commonly used as a basis for lithotype differentiation, (Nichols and Traverse, 1971; ICCP, 1993).

Based on their liptinite assemblages and vitrinite gelification, the coal suite appears to have accumulated within three broad depositional settings. M1 to M3 contain mostly terrestrial liptinites and their vitrinite is poorly gelified. M4 and M5 contain a higher proportion of aquatic liptinites and exhibit moderate to high gelification. Gelification is very advanced in the remaining primary coal, M6, which has an aquatic dominated liptinite assemblage.

### 5.4.3 Integration of lithotype and micropetrographic evaluations

#### 5.4.3.1 Correlation of criteria

Parallel macropetrographic and micropetrographic investigations using an identical sample set facilitated ready comparison of their characteristics and demonstrated that several of the lithotype and maceral criteria are interrelated (Table 5.9). In particular, the key lithotype parameters of texture and wood content are closely related to maceral-derived cell preservation indices. Relationships also exist between colour and micropetrographic characteristics, including gross maceral composition and gelification.

Table 5.9 Relationships between maceral and lithotype characteristics

| Maceral Characteristic | Lithotype Characteristic |
|---|---|
| GROSS MACERAL ASSEMBLAGE | COLOUR (TEXTURE) |
| High to very high liptinite | Light colour |
| High inertinite | Dark colour. Where inertinite occurs as tissue within the groundmass, hard, brittle, charcoal plates are readily apparent. |
| Well gelified | Dark |
| TISSUE PRESERVATION | WOOD CONTENT/TEXTURE |
| High VPI, high MTI | Wood rich, earthy texture |
| High VPI, low MTI | Wood rare, high groundmass tissue, fibrous texture |
| Low VPI, low MTI | Low wood, low groundmass tissue, earthy texture |
| LIPTINITE ASSEMBLAGE | NON-SPECIFIC |
| Terrestrial/aquatic | No clear correlation. Terrestrial components (i.e. cuticle, suberinite, and resinite) are sometimes macroscopically visible. |
| GELIFICATION | GELIFICATION (COLOUR) |
| | Discernable as gelification advances - coal becomes darker, softer and more homogenous |
| MACERAL ASSEMBLAGE | PHYSICAL PROPERTIES |
| Inertinite dominated | Highly fractured, small hard fragments |
| - | Soft and friable |
| LIPTINITE/INERTINITE CONTENT | HARDNESS |
| Limited correlation, but hard coal associated with both high liptinite and high inertinite | Hard coal |
| TELOVITRINITE TYPE | WOOD TYPE |
| | Fibrous wood (W3) and subaerial root material (W2) tentatively correlated to sub-macerals |

Gross maceral composition shows some correlation with colour at *in situ* moisture and appears particularly sensitive to liptinite content. Bands rich and very rich in liptinite occur as distinctly light and pale coals, respectively. While darker coals have elevated inertinite contents, these varieties are also better gelified, and considering the generally low inertinite abundance, this correlation is somewhat tentative. Advanced gelification can clearly be correlated to darker coals, although in poorly to moderately well gelified members colour differentiation is not apparent.

Tissue preservation relates closely to texture and wood content and probably represents the most critical and direct interrelationship of micropetrographic and macropetrographic characteristics. Groundmass and massive telovitrinite phytoclasts correlate directly with groundmass tissue and wood content, respectively. Consequently, increasing MTI corresponds with progressively more woody coals. In low-MTI coals, increasing VPI correlates directly with an increasingly fibrous texture. However, as MTI increases determination of texture from VPI alone becomes more ambiguous.

Gelification is unique among the characteristics evaluated in that it can be directly assessed by both microscopic and macroscopic means and the findings are directly comparable. However, lithotype assessment is limited to the high gelification range, whereas quantitative evaluation over the full range is possible using maceral data.

A distinctive highly fractured, hard coal is very rich in inertinite and these characteristics can be unambiguously linked. However, macroscopically friable and weakly fractured coals could not be differentiated by any of the micropetrographic characteristics.

Liptinite assemblage is not reflected by any of the key macroscopic features, although some larger terrestrial liptinite fragments including cuticle and resin could occasionally be recognised during lithotype evaluation. Tentative links were established between wood type and some of the telovitrinite sub-macerals defined during the current research.

### 5.4.3.2 Correlation of lithotypes and maceral-defined coals

The parallel lithotype and maceral assessments independently identified a very similar coal suite (i.e. Tables 5.6 and 5.8). In addition, clear relationships exist between most of the key macroscopic and microscopic characteristics used for coal differentiation (Table 5.9). However, some inconsistencies were apparent, with nine and seven coal types defined, respectively.

All seven microscopically defined coals can be directly correlated with those identified using macroscopic criteria (Table 5.10). Discrepancies were noted when attempting to relate the woody lithotypes (i.e. L3 and L4) and an altered lithotype (i.e. L9) to maceral-defined coal types. The former are treated as sub-types of a high MTI, high VPI coal (i.e. M3), while the latter cannot be microscopically detected.

Table 5.10 Comparison of coal types

| Macroscopically-defined Coals From Lithotype Evaluation (Table 5.6) | Microscopically-defined Coals From Maceral Evaluation (Table 5.8) | Coal Facies Nomenclature |
|---|---|---|
| L1 | M1 | Ic |
| L2 | M2 | Ib |
| L3 & L4 | M3 | Ia |
| L5 | M4 | IIa |
| L6 | M5 | IIb |
| L7 | M6 | III |
| L8 | M7 | IVa |
| L9 | Not detected | IVb |

Note: The designations of coal type presented in Tables 5.6 to 5.8 are interim assessments. Hereafter nomenclature follows the facies classification elaborated in Chapter 6.

Of the earthy lithotypes, the light member L1 is equivalent to the liptinite-rich M1 coal and the wood-rich L3 and L4 varieties are equivalent to high MTI-differentiated M3 coal. The woody coal lithotypes (i.e. L3 and L4) are distinguished primarily on the basis of wood morphology, but these differences could not be clearly differentiated microscopically. The remaining earthy, low-tissue, low-wood lithotype L2 equates to the low-VPI, low-MTI, micropetrographically-defined M2 coal.

The dark, fibrous lithotypes L5 and L6 containing abundant groundmass tissue fragments, but little wood are correlated with the high-VPI, low-MTI coals M4 and M5. Furthermore, the more fibrous, charcoal-rich L6 lithotype could be specifically related to the elevated inertinite levels in M5.

A strong correlation exists between the dark, very earthy and highly gelified L7 lithotype and the telovitrinite-poor, very highly gelified, microscopically-defined M6 coal.

The fractured and fragmented L8 lithotype correlates with the macrinite-rich coal type, M8. The remaining lithotype, L9, displays evidence of weathering which has affected its physical properties, but does not appear to have substantially modified its micropetrographic characteristics. L9 was therefore retained in the coal type suite, but is unique in that its unambiguous identification is possible only by macroscopic means.

### 5.4.4 Coal facies of the Bowmans and Lochiel Deposits

Eight distinct coal facies have been defined using a combination of micropetrographic and micropetrographic criteria. Each is thought to reflect accumulation under a unique set of depositional conditions. Distinguishing maceral and lithotype criteria used for facies identification, together with facies nomenclature, are summarised in Table 5.11.

Table 5.11 Coal facies summary showing key maceral and lithotype criteria

| Facies * | Maceral Criteria | | | | | Lithotype Criteria | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Maceral Content** | **Tissue Preservation** | **Tissue Size** | **Gelification** | **Liptinite Assemblage** | **Tissue Concentration** | **Tissue Size** | **Texture** | **Colour** | **Fracturing** |
| **Ia** | High vitrinite | **Excellent** | **Massive** | Low | Terrestrial | **High** | **Massive** | Earthy | Medium | - |
| **Ib** | **High liptinite** | **Poor** | Groundmass | Low | **Terrestrial** | **Low** | Groundmass | **Earthy** | Medium | - |
| **Ic** | **Abundant liptinite** | Very poor | Groundmass | Low | Terrestrial | **Low** | Groundmass | Earthy | **Pale/ light** | - |
| **IIa** | High vitrinite | **Good** | **Groundmass** | Mod | **Mixed** | **Mod to high** | **Groundmass** | Mod. fibrous | Dark | - |
| **IIb** | **Moderate inertinite, low liptinite** | **Excellent** | **Groundmass** | High | **Aquatic** | **High** | **Groundmass** | **Very fibrous** | Dark | - |
| **III** | High vitrinite | Poor | Groundmass | **Very high** | **Aquatic** | **Low** | Groundmass | **Very earthy** | **Dark** | - |
| **IVa** | **Abundant inertinite** | Variable | Variable | Variable | Variable | Variable | Variable | Variable | Dark | **Fragmented, hard** |
| **IVb** | Variable | Variable | Variable | Variable | Variable | Variable | Variable | Variable | Dark | **Friable** |

Note: Critical parameters for identification are highlighted in bold font
Coal facies are based on the Lochiel Deposit where the full suite occurs
* Coal facies nomenclature is elaborated in Chapter 6 and used in all subsequent discussion of coal types

Differentiation and definition of the coal facies suite realises the primary objective of this chapter. An in-depth consideration of the attributes of each facies in the classification is presented in Chapter 6, while the occurrence and distribution of these facies is outlined in Chapter 7.

## 5.5 COMPARISON WITH OTHER BROWN COAL DEPOSITS

Well documented brown coal deposits include those of the Gippsland Basin, Victoria and Lower Rhine Embayment, Germany. The former have been extensively investigated and documented (George, 1975, 1982; Holdgate *et al.*, 1995; Holdgate *et al.*, 2000) and are of particular interest due to their temporal and spatial proximity to those of the northern St. Vincent Basin. A brief discussion of possible relationships between coal varieties and differentiation systems follows.

The Eocene to Miocene coals of the Gippsland Basin and, more specifically, those of the Latrobe Valley have been described using a lithotype system based primarily on the air-dried colour (George 1975, 1982). The coal varieties so defined include dark, medium-dark, medium-light, light and pale (Table 5.12; see also Section 2.4.3). This system therefore differs somewhat in concept from that developed during the current study and is not specifically related to depositional environment (cf. Hagemann and Hollerbach, 1980; Hagemann and Wolf, 1987; George and Mackay, 1991). However, maceral information and descriptive data, in addition to quantitative colour measurements collected during this project have enabled a limited comparison of their respective coal types.

While precise equivalence for all primary types cannot be established, some relationships are apparent (Table 5.12; Figure 5.6), with the best correlations being those at the two extremities of the colour range, especially the pale/light lithotypes.

Table 5.12 Comparison of brown coals in the St. Vincent Basin and Latrobe Valley

| **Bowmans and Lochiel Deposit Coal Variety Facies (Lithotype/Micropetrographic)** | **Possible Latrobe Valley Lithotype Equivalent (George, 1975, 1982)** | **Confidence in Correlation** |
|---|---|---|
| Ic (L1/M1) | Pale | Very good |
| Ib (L2/M2) | Light/medium-light | Moderate to good |
| Ia (L3/M3) | Medium -light | Moderate |
| Ia (L4/M3) | Medium -light/medium dark/dark | Tentative to moderate |
| L5/M4 | Dark | Moderate |
| L6/ M5 | Dark | Moderate to good |
| L7/M6 | Dark | - |

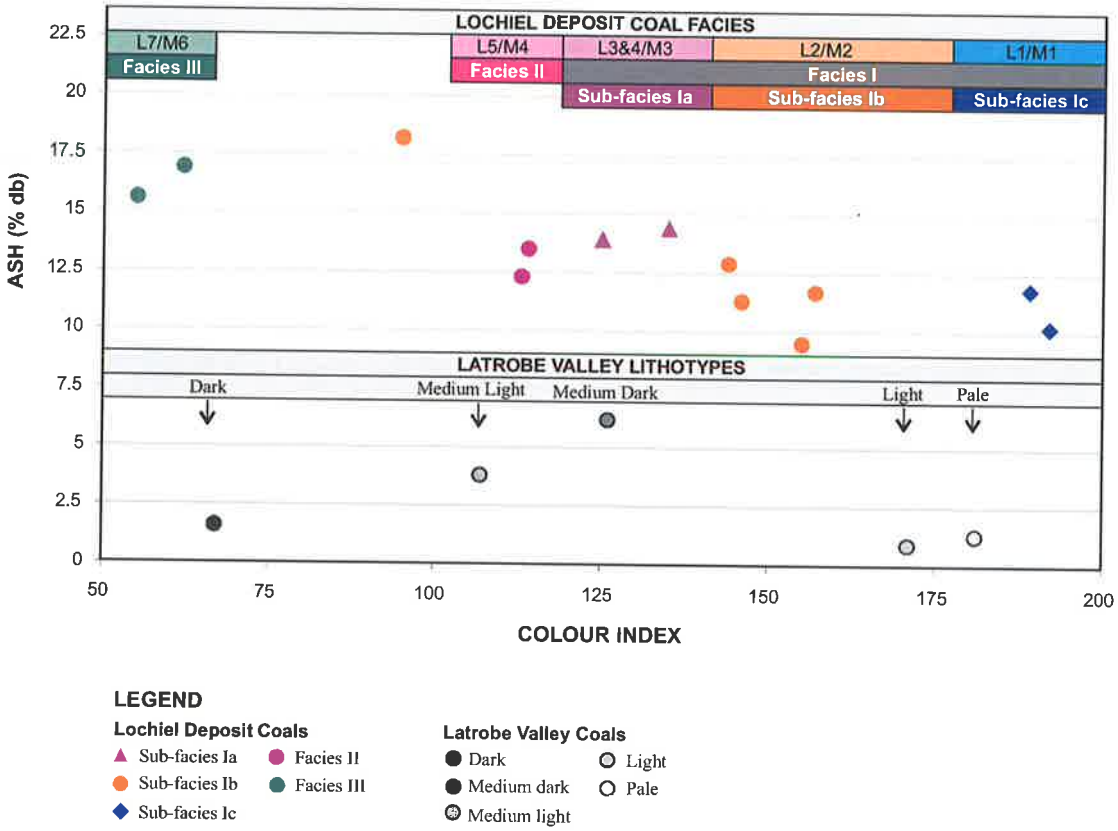



Figure 5.6 Colour index comparison

The characteristics of the L1/M1 coal appear to closely match those of the "pale layers" as described by George (1972, 1975, 1982) in the Latrobe Valley coals and Stach *et al.* (1982) and Teichmuller (1989) in the German brown coals. In particular, the colour, abundant liptinite, bituminitic groundmass, low wood and tissue contents, elevated funginite and low gelification clearly differentiate this variety and result in their definitive correlation. The L2/M2 coal exhibits some similarities to the light and medium light lithotypes defined by George (1975, 1982), although this correlation is less definitive. This similarity is manifest in their highly variable but low overall abundance of wood (with large fragments most common), moderate liptinite content and low gelification of vitrinite. Both correlations between the Lochiel Deposit and Latrobe Valley coals are supported by their comparative colour index measurements (Figure 5.6).

Similarities exist between the L5/M4 and L6/M5 coals of the St. Vincent Basin and the dark lithotypes of the Latrobe Valley, notably their elevated gelification, abundant small tissue and low liptinite contents, together with slightly increased inertinite, particularly fusinite, in some dark coals (George, 1975; Kershaw *et al.*, 1991). This relationship is also supported by their low Colour Index values (Figure 5.6). However, while the Lochiel and Bowmans coals contain little wood, a moderate wood content is typical of the dark Latrobe Valley lithotype.

Correlations involving woody coals are more tentative as this component occurs over a wide range of Latrobe Valley coals, but is restricted to one variety in the Lochiel/Bowmans suite,

(i.e. L3+L4/M3). Precise equivalence to a single lithotype therefore does not exist and L3+L4/M3 probably spans the medium-light, medium-dark and dark varieties, all of which have a significant wood content (George, 1975, 1982) and similar Colour Index values (Figure 5.6). The medium-light Latrobe Valley lithotype with its moderate liptinite content (including significant resinite and suberinite) possibly best relates to the coal distinguished by large and erratically distributed woody fragments at Lochiel/Bowmans, whereas those with lower liptinite contents and well-gelified woody tissue may better equate to the medium-dark (and dark) Victorian coals.

The highly gelified, L7/M6 coals from Lochiel and Bowmans have no clear equivalent among the Latrobe Valley lithotypes (George 1975, 1982). However, if present these would fall into the dark lithotype category based on Colour Index measurement (Figure 5.6). Coals with similar characteristics are frequently reported and sometimes classified as sapropelic (Taylor *et al.*, 1998).

In the texture-based lithotype classification the scheme developed by Francis (1961), the earthy coals are possibly represented by L1-L2; fibrous types by L5-L6; woody coal by L3; and amorphous coal by L7. Another brown coal classifications is the ICCP (1993) system in which the L3+L4/M3 coals are likely to be equivalent to the xylite-rich lithotype, the L5/M4 and L6/M5 varieties would fall within the charcoal-rich lithotype, while the remainder of the primary coals probably equate to the matrix lithotype.

## 5.6 SUMMARY

Coal differentiation criteria were established using a combination of macroscopic (i.e. lithotype) and microscopic (i.e. maceral) characteristics to differentiate eight distinct facies. Each of these brown coal facies is thought to reflect a unique local palaeoenvironment.

Key lithotype characteristics included texture, wood content and fracturing, while important maceral criteria included gross maceral composition, tissue preservation, liptinite composition and vitrinite gelification. Inter-relationships exist between many of these properties such that macropetrographically and micropetrographically-defined coals can be directly correlated. Correlations to other widely-used classifications are apparent, although fewer brown coal lithotypes are recognised in alternative schemes.

## PLATE 5.1
## LITHOTYPE CRITERIA
## GROUNDMASS TEXTURE TYPES

a Very earthy: Tissue absent (dark, conchoidal fracture).
*Hand specimen, Lochiel Deposit, V674 - 32.75 m, (L535), facies III.*

b Very earthy: Tissue rare (dark).
*Hand specimen, Lochiel Deposit, V701 - 51.40 m, (L377), facies III.*

c Earthy: Some fine tissue and wood.
*Hand specimen, Lochiel Deposit, S12 - 4.65 m, (111), sub-facies Ib.*

d Earthy to weakly fibrous: Occasional fine tissue.
*Hand specimen, Lochiel Deposit, V706 - 57.20 m, (L548), sub-facies Ib.*

e Moderately fibrous: Dark and light platy tissue.
*Hand specimen, Lochiel Deposit, V703 - 64.40 m, (L383), sub-facies IIb.*

f Moderately fibrous: Dark and light platy tissue.
*Hand specimen, Lochiel Deposit, V691 - 54.70 m, (L372), sub-facies Ib.*

g Fibrous: Abundant dark platy tissue aligned parallel to bedding.
*Hand specimen, Lochiel Deposit, V706 - 56.60 m, (L546), sub-facies IIb.*

h Very fibrous: Abundant dark, platy tissue aligned parallel to bedding including charcoal fragments.
*Hand specimen, Lochiel Deposit, V662 - 29.80 m, (L391/P6), sub-facies IIb.*

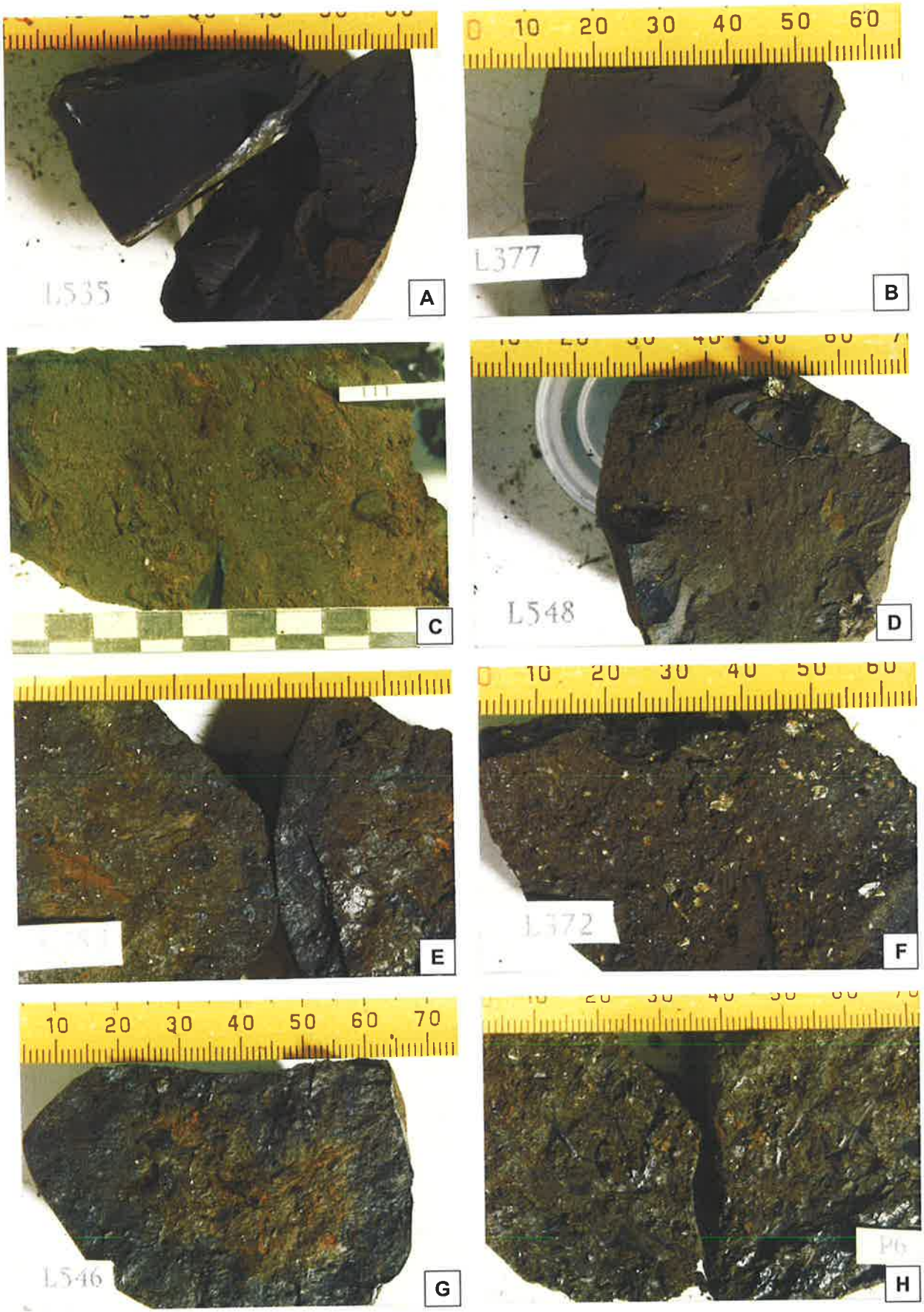



**PLATE 5.1**

**PLATE 5.2**
**LITHOTYPE CRITERIA**
**WOOD PARTICLE TYPES**

a W1: Round, approximately 1 - 1.5 mm diameter (within a dark, high mineral coal).
*Hand specimen, Lochiel Deposit, V662 - 19.10 m, (P1), sub-facies Ia.*

b W1: Small fragments of various morphologies.
*Hand specimen, Lochiel Deposit, V703 - 63.00 m, (L380), sub-facies Ia.*

c W2: Single elongate fragment, approximately 25 - 30 mm by 5 - 10 mm, shown parallel to the long axis, with a thin light brown to reddish brown (possibly suberinitic) covering.
*Hand specimen, Lochiel Deposit, V672 - 37.70 m, (L504), sub-facies Ia.*

d W2: Cross sectional view through an elongate fragment, approximately 10 mm by 5 mm.
*Hand specimen, Lochiel Deposit, V670 - 36.60 m, (P9), sub-facies Ia.*

e W3: Single large fragment shown parallel to long axis, demonstrating a tough, poorly gelified and fibrous form.
*Hand specimen, Lochiel Deposit, S12 - 0.70 m, (102), sub-facies Ia.*

f W3: Large fragments of various morphologies.
*Hand specimen, Lochiel Deposit, S12 - 5.40 m, (113), sub-facies Ia.*

g W3: Single fragment in cross section, showing a tough, poorly gelified and fibrous form.
*Hand specimen, Lochiel Deposit, (P13), sub-facies Ia.*

h W3: Large light coloured fragment parallel to long axis, showing a tough, poorly gelified and fibrous form.
*Hand specimen, Lochiel Deposit, S12 - 5.40 m, (113), sub-facies Ia.*

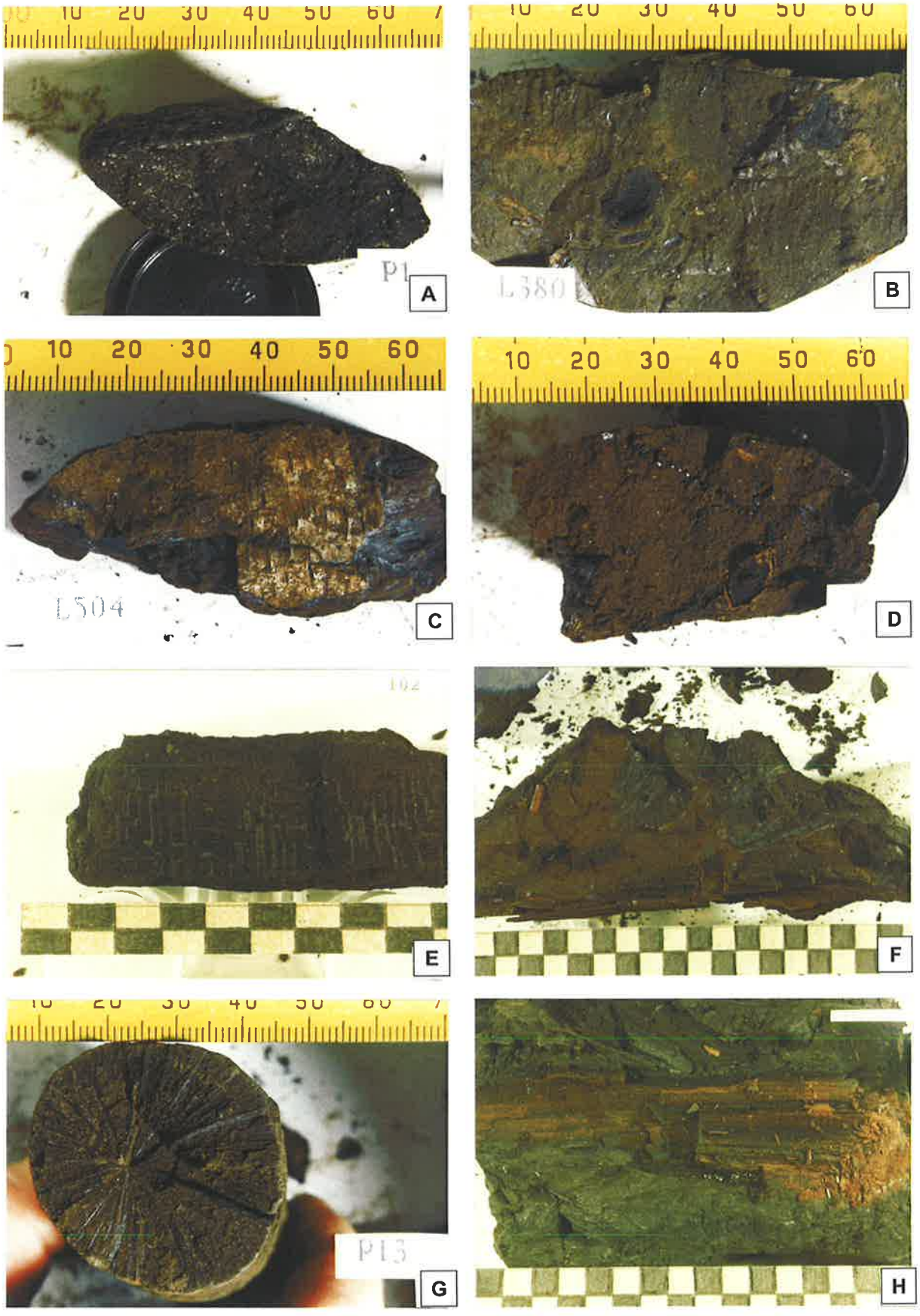



**PLATE 5.2**

**PLATE 5.3**
**LITHOTYPE CRITERIA**
**COLOUR**

a Light: Light to pale brown. Represents a lighter than 'typical' coal colour at *insitu* moisture.

*Hand specimen, Lochiel Deposit, V707 - 56.90 m, (L385), sub-facies Ic.*

b Medium: Medium brown. Represents a 'typical' coal colour at *insitu* moisture.

*Hand specimen, Lochiel Deposit, S12 - 4.65 m, (111), sub-facies Ib.*

c Dark: Dark brown to black. Represents a darker than 'typical' coal colour at *insitu* moisture.

*Hand specimen, Lochiel Deposit, V706 - 56.60 m, (L546), sub-facies IIb.*

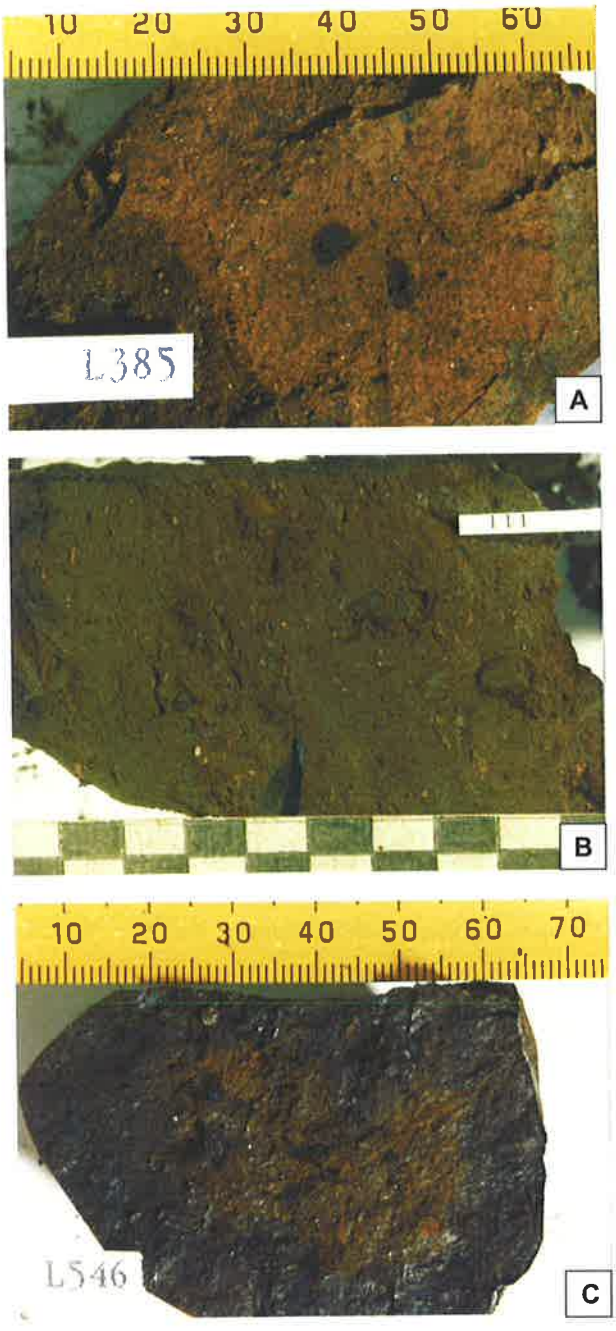



**PLATE 5.3**

## PLATE 5.4
## MACERAL CRITERIA
## CELL PRESERVATION - TELOVITRINITE TYPES

a Groundmass telovitrinite: Small texto-ulminite phytoclasts within an attrinite groundmass.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 86.95 m, sub-facies Ib, negative no. 41/23.*

b Groundmass telovitrinite: Small eu-ulminite phytoclast within an attrinite groundmass.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 82.5 m, sub-facies Ib, negative no. 34/23.*

c Groundmass telovitrinite: Medium texto-ulminite phytoclast within a densinite groundmass. Elongate morphologies are common in facies II coals.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 49, sub-facies IIb, negative no. 28/21.*

d Groundmass telovitrinite: Medium texto-ulminite phytoclasts within a densinite groundmass.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 31, sub-facies IIb, negative no. 40/1.*

e Groundmass telovitrinite: Large texto-ulminite phytoclast within a densinite groundmass.
*Photomicrograph, white reflected light, Lochiel Deposit, V706 - 56.60 m, (L546), sub-facies IIb negative no. 39/14.*

f Groundmass telovitrinite: Large eu-ulminite phytoclast within a densinite groundmass.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 49, sub-facies IIb, negative no. 28/5t.*

g Massive telovitrinite: Massive texto-ulminite phytoclast (i.e. single grain devoid of detrovitrinite).
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 85.5 m, sub-facies Ia, negative no. 20/13.*

h Massive telovitrinite: Massive texto-ulminite phytoclast (i.e. single grain devoid of detrovitrinite).
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 85.5 m, sub-facies Ia, negative no. 20/11.*

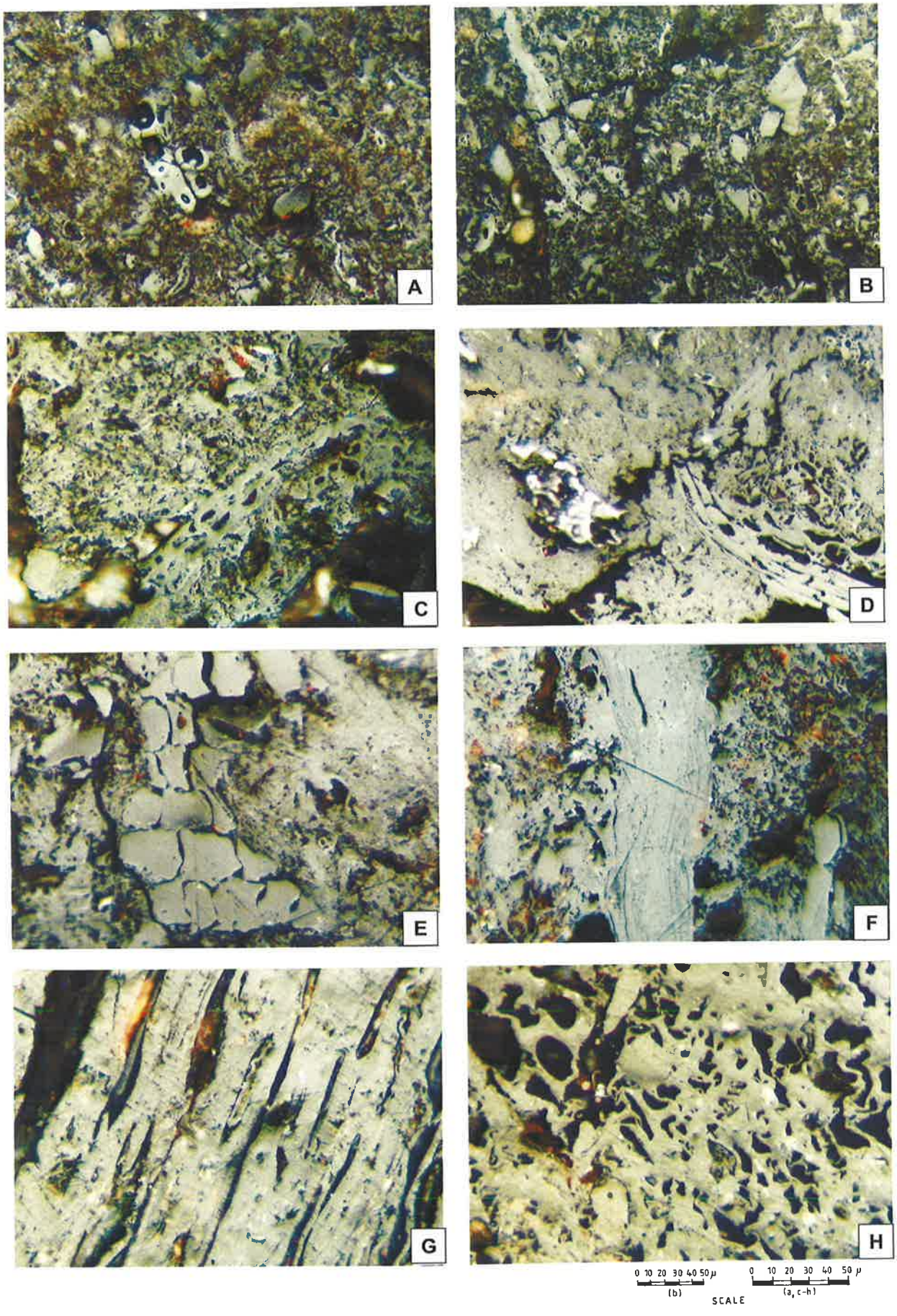



**PLATE 5.4**

## PLATE 5.5
## MACERAL CRITERIA
## CELL PRESERVATION - LIPTINITE

a Low: Abundant fine liptodetrinite of relative even particle size, with only minor amounts of readily identifiable liptinite macerals.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V672 - 34.90 m, (L500), sub-facies IVb, negative no. 41/6.*

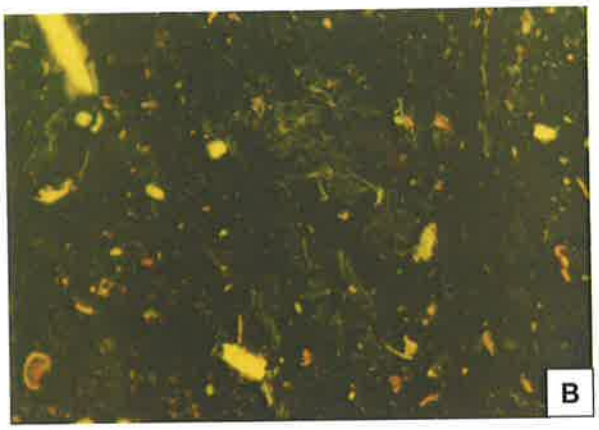
b Low to moderate: Fine liptodetrinite with some discernable, intact liptinite phytoclasts.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 72, sub-facies Ia, negative no. 35/23.*

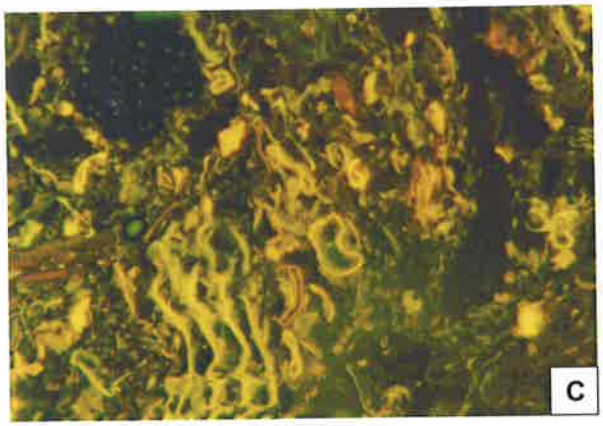
c Moderate: Several distinct intact liptinite macerals and fine liptodetrinite.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 60, sub-facies Ib, negative no. 41/6.*

d Moderate to high: Mainly intact liptinite phytoclasts, with only minor liptodetrinite.
*Photomicrograph, fluorescence mode, Bowmans Deposit, B28 - 16, sub-facies Ib, negative no. 31/17.*

e High: Essentially all intact and readily identifiable liptinite macerals.
*Photomicrograph, fluorescence mode, Bowmans Deposit, B28 - 6, sub-facies Ic, negative no. 31/23.*

f Very high: Large intact liptinite phytoclasts and an absence of liptodetrinite.
*Photomicrograph, fluorescence mode, Bowmans Deposit, B28 - 54, sub-facies IIa, negative no. 34/16.*



0 10 20 30 40 50 μ (b-f)

0 10 20 30 40 50 μ (a)

SCALE

**PLATE 5.5**

**PLATE 5.6**
**MACERAL CRITERIA**
**GELIFICATION**

a Poorly gelified: Loosely packed and largely ungelified vitrinite, with a high porosity.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 86.95 m, sub-facies Ib, negative no. 35/9.*

b Moderately gelified: Partially gelified vitrinite with individual particles clearly discernable, low to moderate porosity.
*Photomicrograph, white reflected light, Bowmans Deposit, B28 - 16, 68.50 m, sub-facies IIa, negative no. 31/16.*

c Well gelified: Individual vitrinite particles are no longer clearly discernable, very low porosity.
*Photomicrograph, white reflected light, Lochiel Deposit, V673 - 27.9 m, (LP6/SECV-1), facies III, negative no. 26/5.*

SCALE

0 10 20 30 40 50μ

(c)

0 10 20 30 40 50μ

(a,b)

**PLATE 5.6**

## PLATE 5.7
## MACERAL CRITERIA
## LIPTINITE ASSEMBLAGE

a Terrestrial: Large resinite and suberinite phytoclasts.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 71, sub-facies Ia, negative no. 40/21.*

b Terrestrial: Large thick cutinite "L" with smaller resinite and suberinite fragments, and sporinite. (Note: Sporinite occurs in both terrestrial and aquatic assemblages).
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 73, sub-facies Ia, negative no. 41/3.*

c Terrestrial: Suberinite, resinite and liptodetrinite with some sporinite.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 60, sub-facies Ib, negative no. 41/6.*

d Terrestrial: Rich in large resinite with fragments of suberinite, cutinite "L" (top of field of view) liptodetrinite and sporinite.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 60, sub-facies Ib, negative no. 41/8.*

e Aquatic: Very thin, long and well preserved cutinite "M", with minor liptodetrinite.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V704 - 28, sub-facies IIb, negative no. 22/4.*

f Aquatic: Alginite and sporinite, with very low liptodetrinite.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V706 - 55.65 m, (L543), facies III, negative no. 38/24.*

g Aquatic: Sporinite with minor liptodetrinite. (Note: Sporinite may represent a significant liptinite in aquatic settings).
*Photomicrograph fluorescence mode, Lochiel Deposit, V673 - 27.90 m, facies III, negative no. 26/2.*

h Aquatic: Fine cutinite "N" and sporinite with low liptodetrinite.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V674 - 32.75 m, (L535), facies III, negative no. 38/22.*

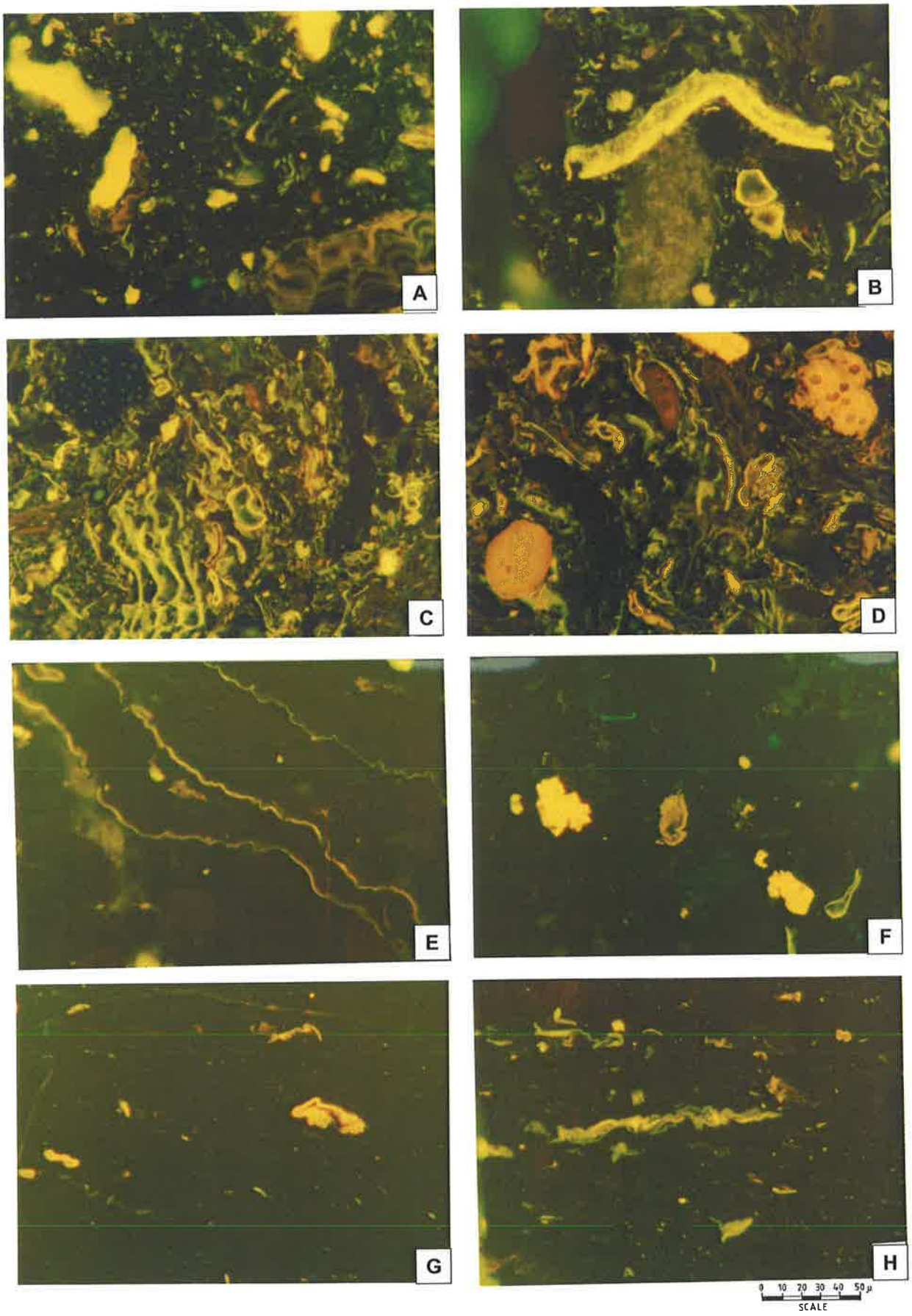



**PLATE 5.7**

**PLATE 5.8**
**MACERAL CRITERIA**
**CUTINITE VARIETIES**

a Cutinite "L": Thick, highly fluorescing cutinite, closely associated with terrestrial liptinites and wood rich coals. The phytoclast shown (~10 by 150 μm in size) is typical of this variety.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 73, sub-facies Ia, negative no. 41/2.*

b Cutinite "M": Very thin, long and well preserved cutinite displaying dull fluorescence. Preservation of this variety in fine phytoclasts up 250 μm long is common in facies II coals.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V704 - 28, sub-facies IIb, negative no. 22/4.*

c Cutinite "N": Fine cuticular associations, often ~100 to 150 μm in length. This variety is restricted to aquatic associations and is relatively uncommon.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V674 - 32.75 m, (L535), facies III, negative no. 38/22.*

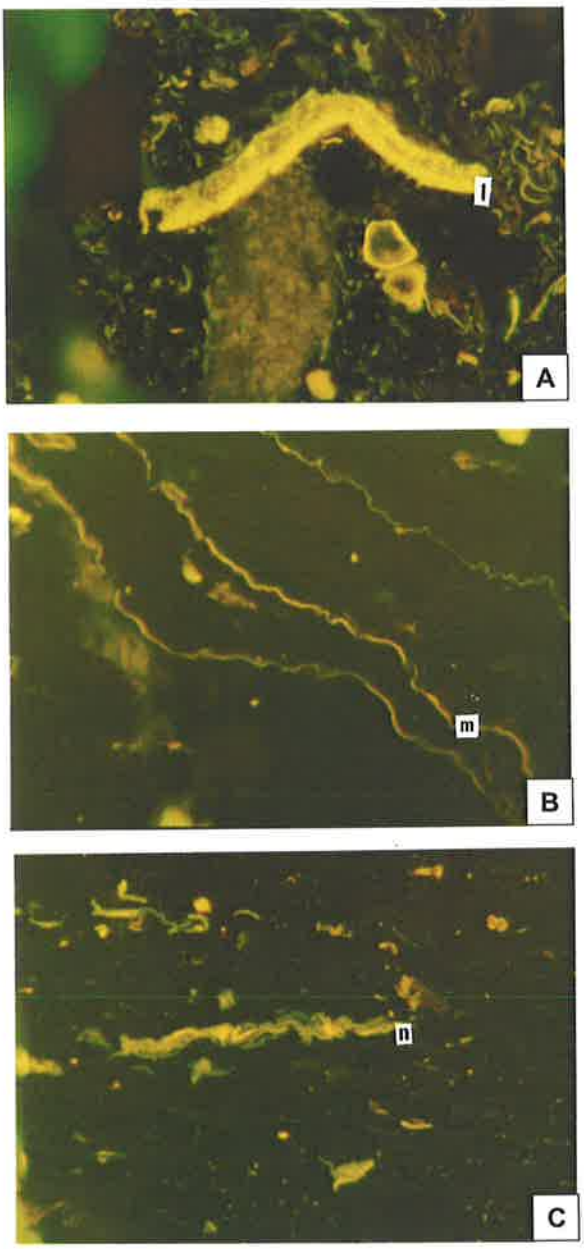
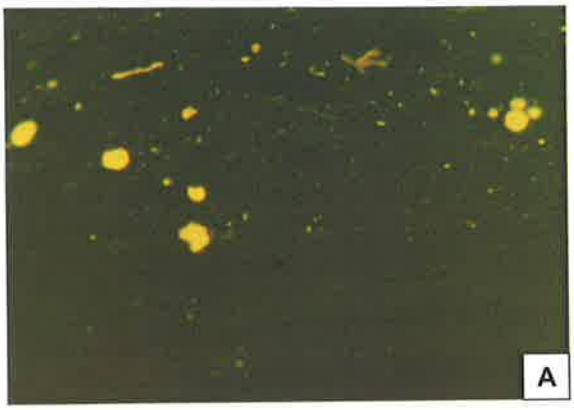


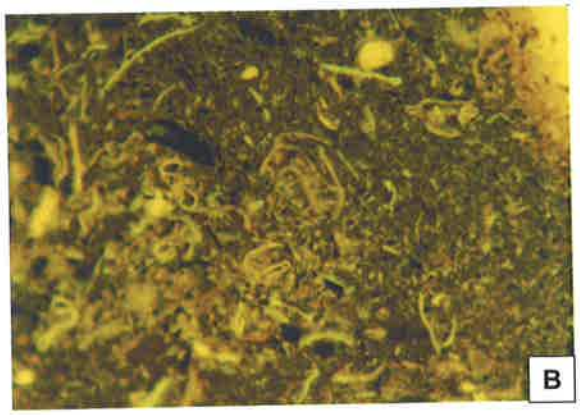

**PLATE 5.8**

**PLATE 5.9**
**MACERAL CRITERIA**
**SECONDARY LIPTINITE**

a Fluorinite: Rounded, isolated of bodies showing intense fluorescence.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V695 - 48.00 m, (L376), facies III, negative no. 39/7.*

b Bituminite: Very fine grained groundmass of low fluorescencing bituminite within a liptinite dominated coal.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 27/25.*




SCALE
0 10 20 30 40 50 μ

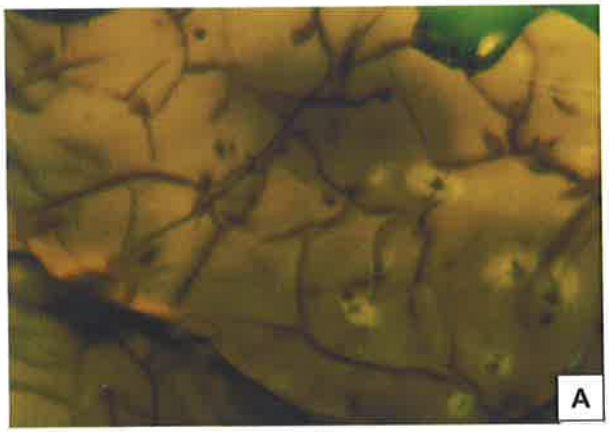
**PLATE 5.9**

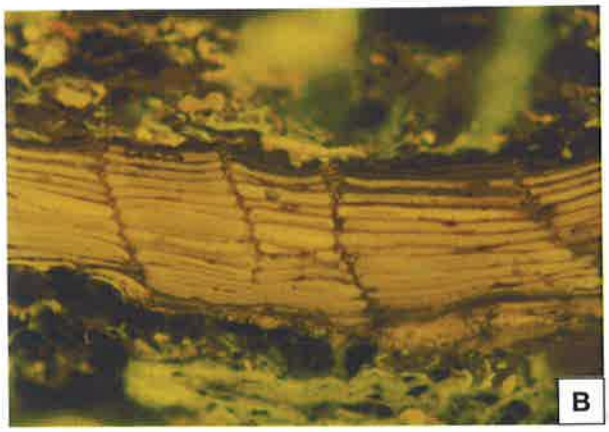
**PLATE 5.10**
**MACERAL CRITERIA**
**RESINITE VARIETIES**

a Resinite "C": Large phytoclast consisting entirely of resinite. This variety possibly relates to macroscopically visible resin and is best developed in Bowmans coals.
*Photomicrograph, fluorescence mode, Bowmans Deposit, B5 - 69.9 m, sub-facies Ib, negative no. 9/7.*

b Resinite "D": Elongate, rounded resinite phytoclasts generally ~10 - 100 μm in length, occurring in cellular associations.
*Photomicrograph, fluorescence mode, Bowmans Deposit, B28 - 6, sub-facies Ic, negative no. 31/21.*

c Resinite "B": Rounded, elongate resinite phytoclasts generally ~10 to 100 μm in length, within a detrovitrinite groundmass. The disseminated nature of this individual phytoclast is used to differentiate resinite "B" from resinite "D".
*Photomicrograph, fluorescence mode, Bowmans Deposit, B28 - 48, sub-facies IIa, negative no. 33/12.*



SCALE

0 10 20 30 40 50 μ
(a)

0 10 20 30 40 50 μ
(b,c)

**PLATE 5.10**

## PLATE 5.11
## MACERAL CRITERIA
## SUBERINITE VARIETIES

a Suberinite "C": Thin, dark, suberinite "C" phytoclast in lower portion of the plate with essentially open, empty cell lumens.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 86.95 m, sub-facies Ib, negative no. 41/20.*

b Suberinite "C": Dull brown fluorescing suberinite "C". Occurrence of this variety is mainly restricted to Bowmans coals.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.11a, Bowmans Deposit, B5 - 86.95 m, sub-facies Ib, negative no. 41/22.*

c Suberinite "C": Large phytoclast with thin, dark grey suberinite "C" and light grey vitrinite cell infilling.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 76.4 m, sub-facies IIb, negative no. 14/9.*

d Suberinite "C": Dull brown fluorescing suberinite "C".
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.11c, Bowmans Deposit, B5 - 76.4 m, sub-facies Ib, negative no. 14/10.*

e Suberinite: Large suberinite phytoclast. This is the most common form of suberinite in both deposits.
*Photomicrograph, white reflected light, Lochiel Deposit, V672 - 37.70 m, (L504), sub-facies Ia, negative no. 37/6.*

f Suberinite: Large suberinite phytoclast displaying moderate fluorescence.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.11e, Lochiel Deposit, V672 - 37.70 m, (L504), sub-facies Ia, negative no. 37/7.*

g Suberinite: Large phytoclast of thick walled suberinite.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 83.55 m, sub-facies Ib, negative no. 13/15.*

h Suberinite: Large phytoclast of thick walled suberinite displaying moderate fluorescence.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.11g, Bowmans Deposit, B5 - 83.55 m, sub-facies Ib, negative no. 13/17.*

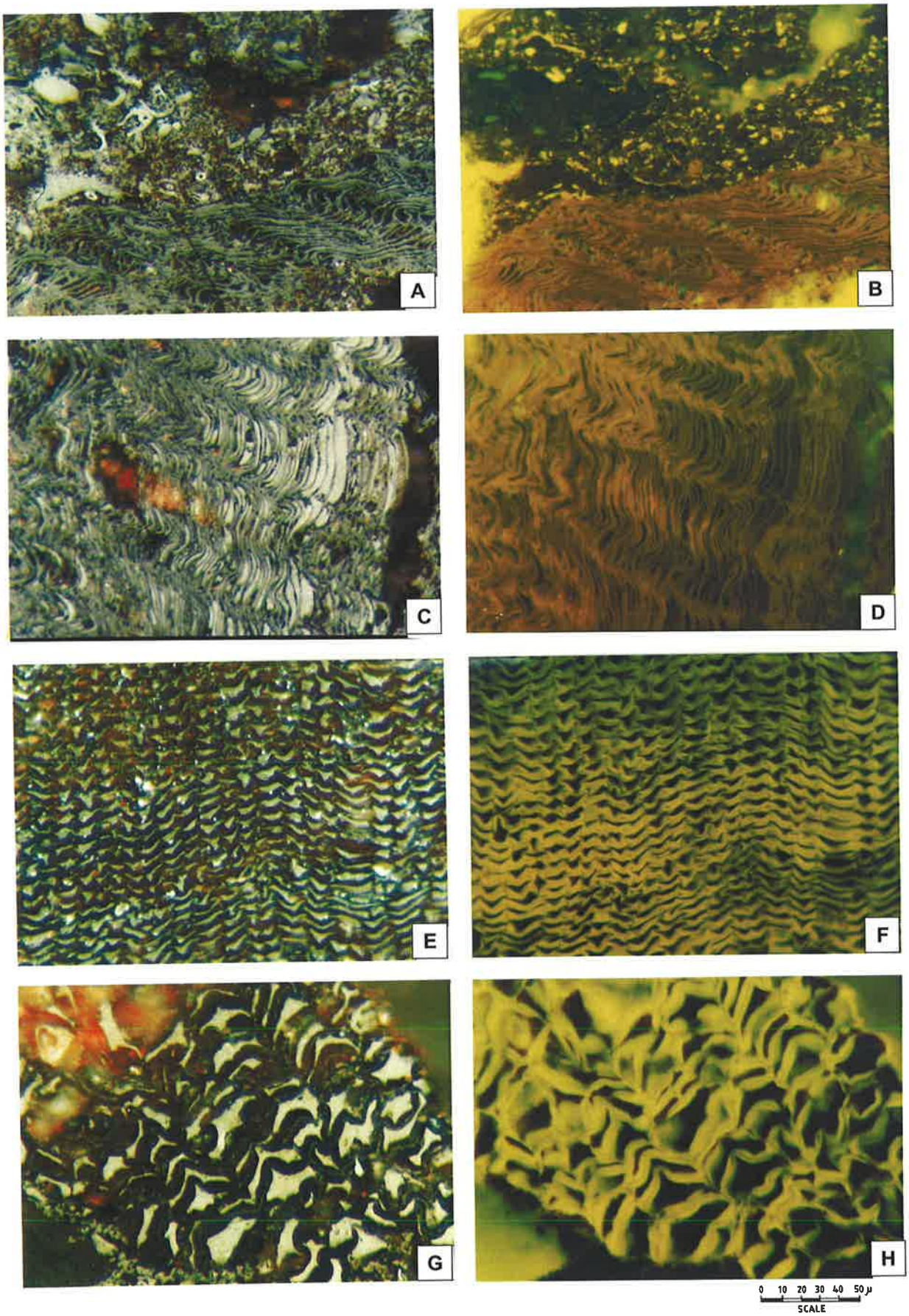



**PLATE 5.11**

## PLATE 5.12
## MACERAL CRITERIA
## EU-ULMINITE "T"

a Eu-ulminite "T": Large phytoclast of eu-ulminite "T" with cell walls clearly visible and rare open pores.
*Photomicrograph white reflected light, Lochiel Deposit, L402, sub-facies Ia, negative no. 37/12.*

b Liptinite within eu-ulminite "T": Very fine liptinite, possibly resinite.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.12a, Lochiel Deposit, L402, sub-facies Ia, negative no. 37/13.*

c Eu-ulminite "T": Large phytoclasts of eu-ulminite "T" showing some cell wall remnants, limited porosity and grainy appearance.
*Photomicrograph, white reflected light, Lochiel Deposit, L402, sub-facies Ia, negative no. 37/16.*

d Liptinite within eu-ulminite "T": Very fine liptinite, possibly resinite.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.12c, Lochiel Deposit, L402, sub-facies Ia, negative no. 37/17.*

e Eu-ulminite "T": Large phytoclast of eu-ulminite "T" with no discernable cell walls and a very grainy appearance. This is the most commonly displayed form the sub-maceral
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 71, sub-facies Ia, negative no. 40/17.*

f Liptinite component in eu-ulminite "T": Very fine liptinite, possibly resinite.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.12e, Lochiel Deposit, V714 - 71, sub-facies Ia, negative no. 40/18.*

g Eu-ulminite "T": Large phytoclast of eu-ulminite T, showing rare cell wall remnants, but with a significantly elevated liptinite content.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 80.5 m, sub-facies Ia,* negative no. *15/16.*

h Liptinite component in eu-ulminite "T": Abundant fine liptinite, possibly resinite and bituminite.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.12g, Bowmans Deposit, B5 - 80.5m, sub-facies Ia, negative no. 40/18.*

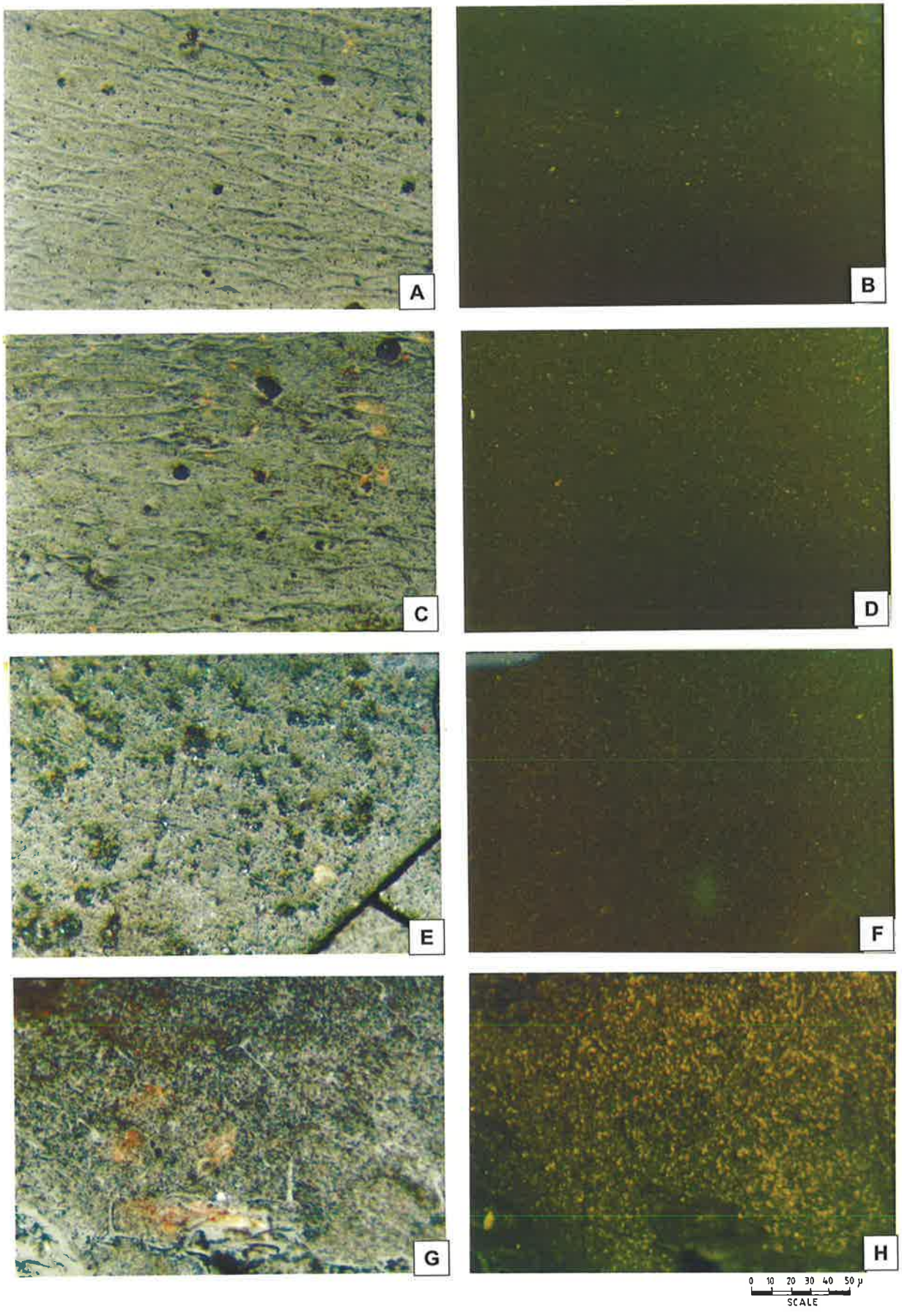



**PLATE 5.12**

## PLATE 5.13
## MACERAL CRITERIA
## MICROTEXTURE "B"

a Microtexture "B": Well gelified, coarse, well sorted corpogelinite, with some funginite and inertinite. Corpogelinite and inertinite abundance is elevated significantly with respect to typical groundmass concentrations.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 74.3 m, sub-facies Ia, negative no. 12/13.*

b Microtexture "B": Well gelified, coarse, poorly sorted corpogelinite, with minor inertodetrinite.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 74.3 m, sub-facies Ia, negative no. 12/14.*

c Microtexture "B": Moderately gelified, medium sized, very well sorted corpogelinite, with minor inertodetrinite.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 72.7 m, sub-facies Ib, negative no. 19/32.*

d Liptinite within microtexture "B": Well sorted liptinite phytoclasts including resinite and sporinite. Liptinite is reduced relative to typical facies I groundmass abundance.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.13c, Bowmans Deposit, B5 - 72.7 m, sub-facies Ib, negative no. 19/33.*

e Microtexture "B": Well gelified, medium to coarse, poorly sorted particles of corpogelinite, with some inertodetrinite.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 76.4 m, sub-facies Ib, negative no. 21/14.*

f Liptinite within microtexture "B": Minor liptinite including resinite and sporinite.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.13e, Bowmans Deposit, B5 - 76.4m, sub-facies Ib, negative no. 21/15.*

g Microtexture "B": Poorly gelified, medium sized, well sorted corpogelinite, with significant porosity.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 72.7 m, sub-facies Ib, negative no. 20/5.*

h Liptinite within microtexture "B": Minor liptinite including resinite, sporinite and possibly telalginite.
*Photomicrograph, fluorescence mode showing identical field of view to Plate 5.13g, Bowmans Deposit, B5 - 72.7 m, sub-facies Ib, negative no. 20/6.*

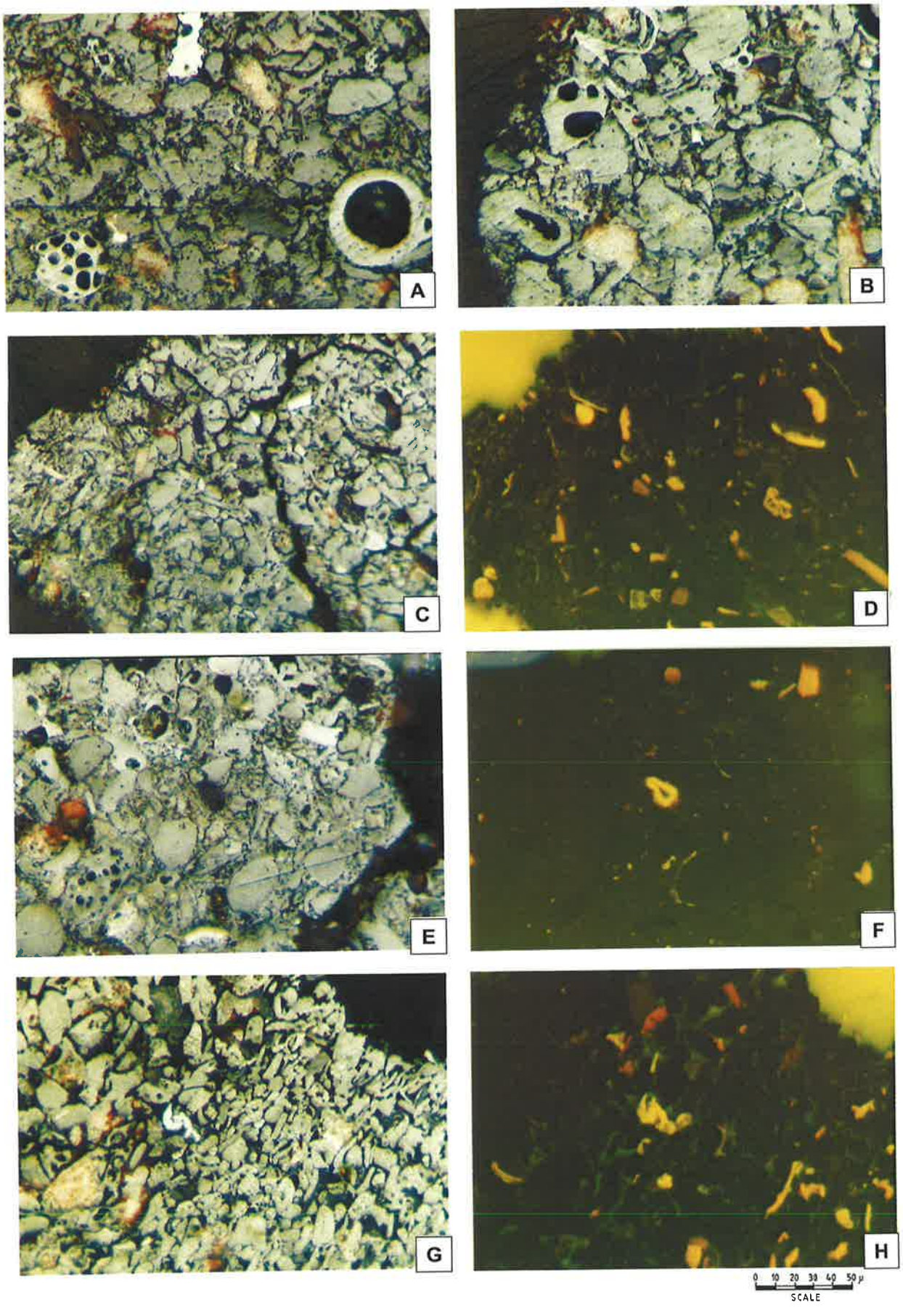



**PLATE 5.13**

# 6 CLASSIFICATION AND LIKELY DEPOSITIONAL SETTINGS OF COAL FACIES

The assignment of coal types to facies groupings and evaluation of their respective palaeoenvironments is the subject of this chapter. The basis of the facies classification, and its nomenclature and applicability, are first outlined. The lithotype, maceral and other distinguishing attributes of each facies and sub-facies are then elaborated, along with their likely palaeoenvironmental implications.

## 6.1 FACIES CLASSIFICATION

### 6.1.1 System and nomenclature

The eight coal types defined in Chapter 5 display specific genetic characteristics and each could be considered a discrete coal facies that accumulated under unique environmental conditions (Taylor *et al.*, 1998). In classifying them, a system involving the minimum number of facies necessary to adequately cover the identified coal types was sought. Similarities between members of the coal suite were therefore used within a hierarchical system of facies and sub-facies categories.

Major variations in petrographic properties were used to define four facies groupings, while a limited number of sub-facies were established in recognition of more subtle compositional changes. Each facies and sub-facies is distinguished by multiple parameters. The four principal groups are designated facies I to facies IV, while sub-facies nomenclature uses the facies name with an alphabetical suffix (e.g. sub-facies Ic for sub-facies "c" of facies I). An overview of the facies classification and key facies and sub-facies attributes is shown in Table 6.1.

Table 6.1 Facies classification system

| Facies | Facies Group Characteristics | Sub-Facies | Sub-Facies Characteristics |
|---|---|---|---|
| I | Terrestrial liptinite assemblage, low gelification, low groundmass tissue | Ia | Abundant wood/telovitrinite |
| | | Ib | High terrestrial liptinite, low wood /telovitrinite |
| | | Ic | Extreme liptinite enrichment |
| II | High groundmass tissue, mixed liptinite assemblage, moderate to high gelification | IIa | Low inertinite, mixed liptinite assemblage |
| | | IIb | Elevated inertinite, predominantly aquatic liptinites, high gelification |
| III | Low groundmass tissue, aquatic liptinite assemblage, high gelification | | |
| IV | Physical or chemical modification of primary coal types | IVa | Abundant inertinite |
| | | IVb | Friable macroscopic habit |

Note: No sub-facies recognised within facies III

The facies classification encompasses all coals from both the Lochiel and Bowmans Deposits. However, the Lochiel Deposit shows considerably greater coal diversity than does Bowmans (i.e. eight types compared to four, respectively), and a wider range of maceral attributes. Furthermore, a higher level of data (particularly lithotype logs) exists for this deposit and may have lead to some unintended bias toward Lochiel in the definition of "typical" facies criteria. Notwithstanding these factors, the classification is considered applicable to both deposits and several parameters indicate that subtle differences exist between them. Such inter-deposit differences are highlighted in the discussion.

### 6.1.2 Petrographic overview

Coals from the Lochiel and Bowmans Deposits are predominantly vitrinite rich but inertinite poor and contain moderate amounts of liptinite. However, maceral group abundance and several other petrographic properties show considerable variation across the facies suite. In particular, features relating to tissue preservation (i.e. telovitrinite content, the size and nature of phytoclasts and the ratio of intact to preserved liptinites), liptinite content and the nature of the liptinite assemblage allow clear differentiation of facies. Notwithstanding its low abundance, the inertinite assemblage also varies markedly between facies.

Lithotype characteristics also exhibit distinct changes with facies. Properties such as texture (ranging from earthy and homogenous with very low groundmass tissue, to very fibrous with abundant groundmass tissue) and wood content (ranging from very low to abundant) are particularly variable and represent the macroscopic expression of tissue preservation. Others such as gelification, colour and hardness also vary between facies, although in a less pronounced manner.

Maceral and lithotype attributes for each facies and sub-facies are summarised in Table 6.2, with in-depth discussion of petrographic characteristics presented with the evaluation of facies types (Sections 6.2 to 6.5). Supporting lithotype logs and maceral point count data are included in Appendices B and C.

Table 6.2 Lithotype and maceral properties of facies and sub-facies

| **Parameter** | **Facies 1** | | | | **Facies II** | | | **Facies III** | **Facies IV *** |
|---|---|---|---|---|---|---|---|---|---|
| | Ia | Ib | Ic | All | IIa | IIb | All | | IVa |
| LITHOTYPE | | | | | | | | | |
| Texture | E (WF) | E (WF) | E | | MF - F | F - VF | | VE | |
| Wood content | High | Low | V. low | | Low | Low | | Low | |
| Colour | LT - MD | LT - MD | PA (LT) | | Dark | Dark | | Dark | |
| Gelification | Mod | Low | Low | | Mod | High | | V high | |
| Hardness | - | - | Mod. | | - | - | | - | High |
| Fracturing | - | - | - | | - | - | | - | High |
| Microbanding | - | - | - | | Weak | Weak | | Mod. | |
| MACERAL % | | | | | | | | | |
| Telovitrinite | 34.5 | 20.4 | 8.8 | **24.3** | 27.1 | 26.7 | **27.0** | **22.1** | - |
| Detrovitrinite | 43.8 | 55.6 | 27.7 | **50.2** | 52.7 | 57.3 | **53.7** | **62.9** | - |
| Gelovitrinite | 5.9 | 7.2 | 4.9 | **6.7** | 7.1 | 5.6 | **6.7** | **3.2** | - |
| *Σ Vitrinite* | *84.3* | *83.2* | *41.4* | ***81.2*** | *86.8* | *89.6* | ***87.5*** | ***88.2*** | - |
| Resinite + suberinite | 6.2 | 5.9 | 7.1 | **6.0** | 5.9 | 1.0 | **4.8** | **1.8** | - |
| Cutinite + sporinite +alginite | 1.7 | 1.4 | 5.5 | **1.8** | 1.4 | 3.1 | **1.9** | **3.0** | - |
| Bituminite | 0.5 | 0.6 | 8.5 | **1.0** | 0.2 | 0.4 | **0.3** | **0.6** | - |
| Fluorinite | - | - | - | - | - | - | - | **0.2** | - |
| Liptodetrinite | 6.4 | 7.1 | 33.4 | **8.3** | 3.9 | 2.7 | **3.6** | **5.0** | - |
| *Σ Liptinite* | *14.7* | *15.1* | *54.6* | ***17.1*** | *11.5* | *7.2* | ***10.5*** | ***10.6*** | - |
| Telo-inertinite | 0.8 | 1.1 | 2.7 | **1.1** | 1.3 | 2.9 | **1.7** | **0.5** | - |
| Detro-inertinite | 0.3 | 0.3 | 1.3 | **0.3** | 0.3 | 0.4 | **0.3** | **0.4** | - |
| Gelo-inertinite | 0.1 | 0.4 | 0.1 | **0.3** | - | - | - | **0.2** | 20-100 |
| *Σ Inertinite* | *1.0* | *1.7* | *4.0* | ***1.6*** | *1.6* | *3.3* | ***2.0*** | ***1.2*** | *20-100* |
| MACERAL INDICES | | | | | | | | | |
| VPI | 42.5 | 26.1 | 22.1 | **31.2** | 33.8 | 31.7 | **33.3** | **26.0** | - |
| LPI | 55.8 | 51.9 | 26.6 | **51.8** | 64.5 | 61.5 | **63.8** | **48.3** | - |
| MTI | 59.7 | 25.5 | 33.2 | **37.0** | 19.6 | 11.8 | **17.8** | **14.9** | - |
| GI-1 | 33.7 | 30.1 | 16.1 | **30.5** | 42.8 | 55.6 | **45.7** | **70.3** | - |
| LEI | 29.1 | 32.1 | 38.9 | **31.5** | 29.5 | 65.0 | **37.5** | **53.0** | - |
| LAI | 3.7 | 3.2 | 17.8 | **4.2** | 2.1 | 5.0 | **2.8** | **8.1** | - |

Key: - = not applicable
* Sub-facies IVb (not included in table) refers to coal defined solely by macroscopic means
Texture abbreviations: VE = very earthy/massive, E = earthy, WF = weakly fibrous, MF = moderately fibrous, F = fibrous, VF = very fibrous
Colour abbreviations: PA = pale, LT = light, MD = medium dark
Numerals = mean values

## 6.2 FACIES I

### 6.2.1 General characteristics and definition of sub-facies

Facies I coals are humic in nature (i.e. derived from plant debris subject to partial degradation by interaction with the atmosphere prior to burial; Ward, 1987) and are distinguished by a low degree of gelification, a moderate to high content of terrestrial liptinites, little groundmass tissue and little to very little inertinite. Large telovitrinite phytoclasts can occur in high concentration. Macroscopic characteristics include an earthy to weakly fibrous texture, a medium (to light) brown colour and the inclusion of assorted woody fragments (Figure 6.1, Appendix C).

Facies I coals have been further differentiated into three sub-facies according to their relative amounts of liptinite and massive telovitrinite (reflected macroscopically by colour and wood content, respectively), abundances of inertinite and secondary liptinite, and degree of tissue preservation (Figures 6.2 and 6.3).

The groundmass components of sub-facies Ia and Ib coals are essentially identical, with their distinction based on the presence of woody material in the former. Sub-facies Ic coals are richer in the most resistant (i.e. liptinite) components and in bituminite, a secondary liptinite. However, the individual primary liptinites in sub-facies Ic coals correlate closely in type and relative abundance to those of sub-facies Ia and Ib.

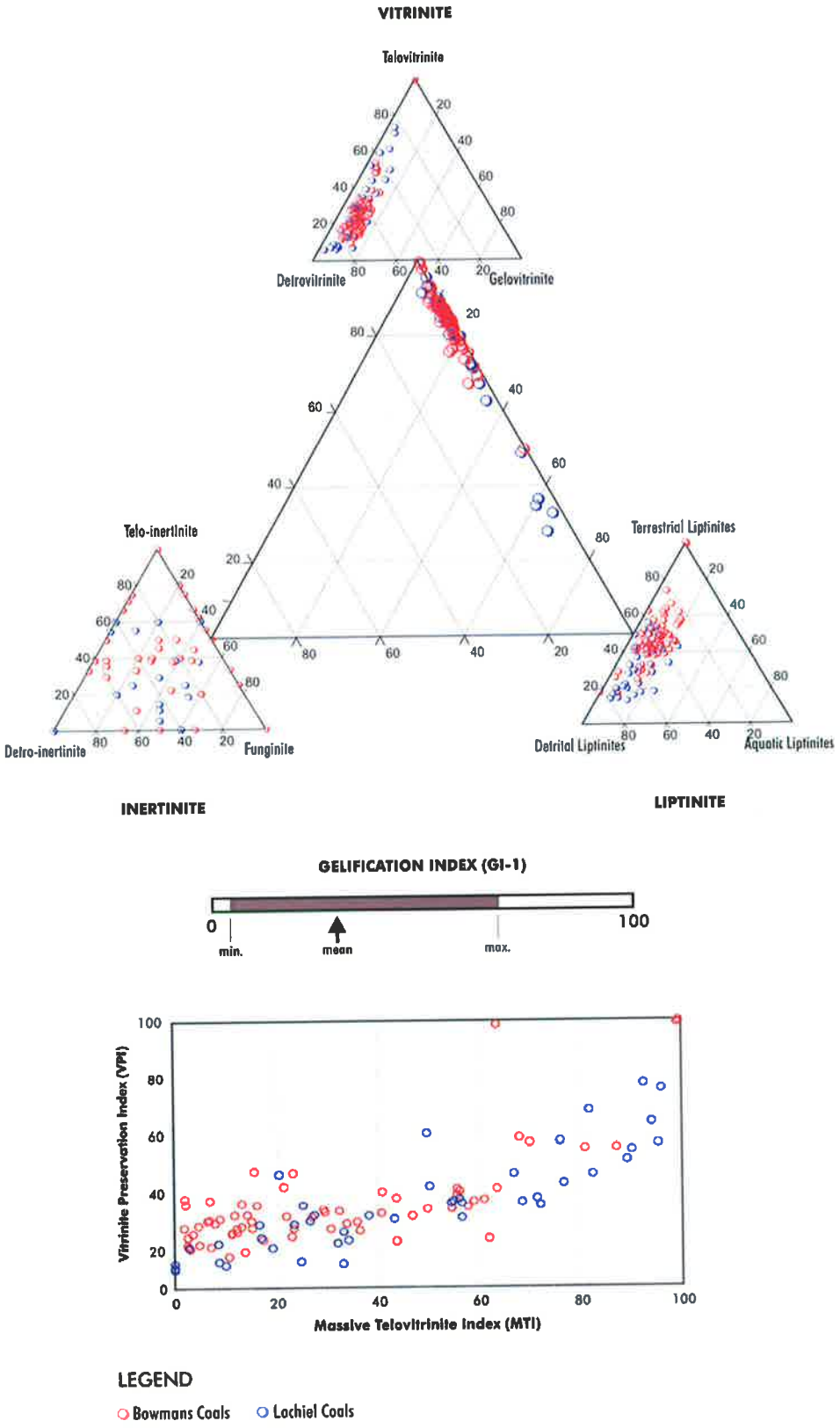
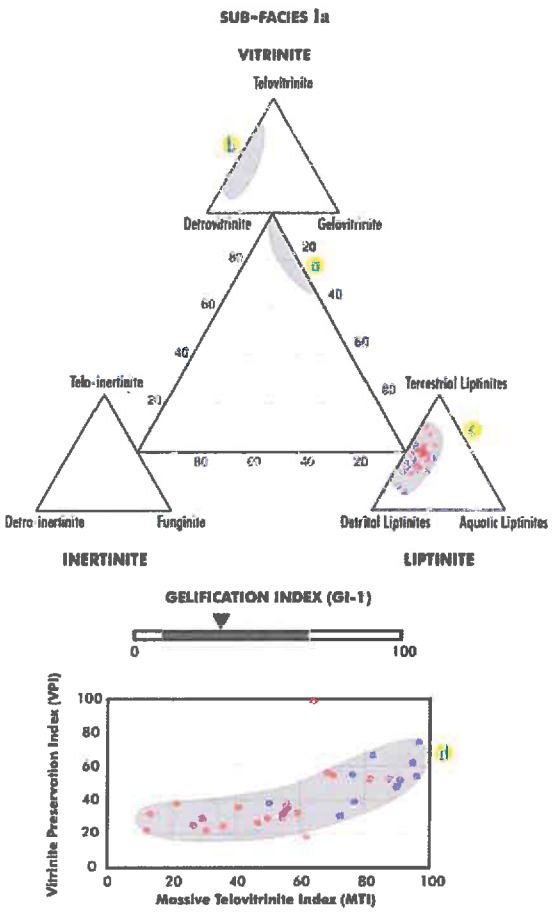
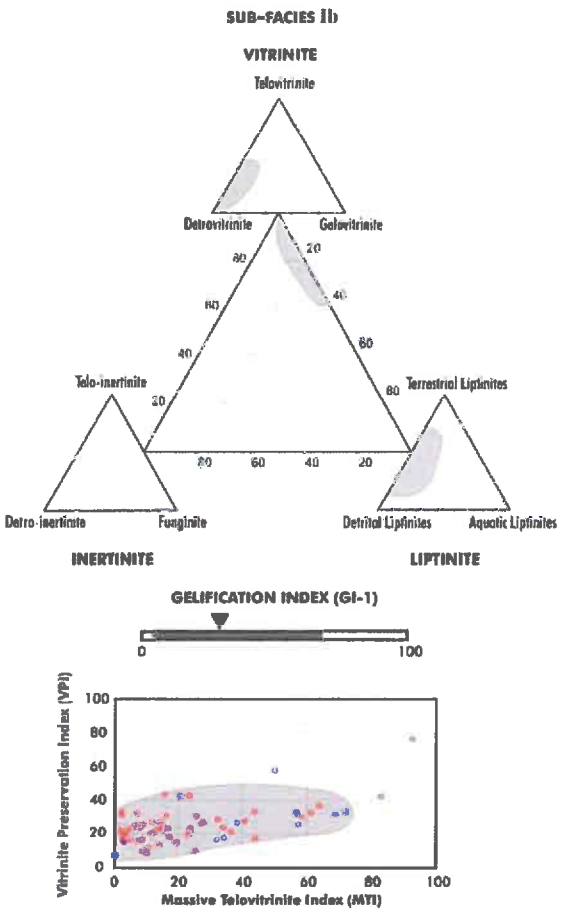
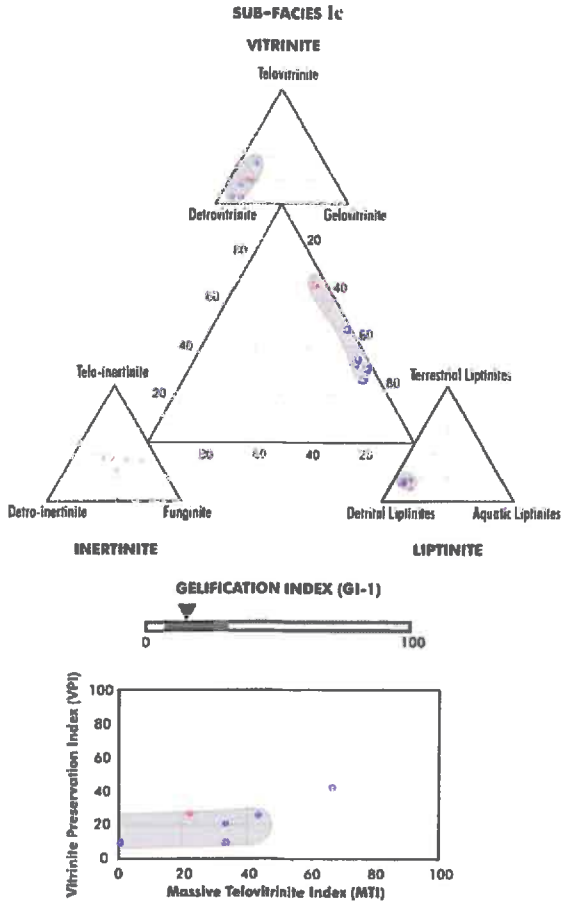



Figure 6.1 Maceral characteristics of facies I coals




LEGEND

Bowmans Coals  Lochiel Coals

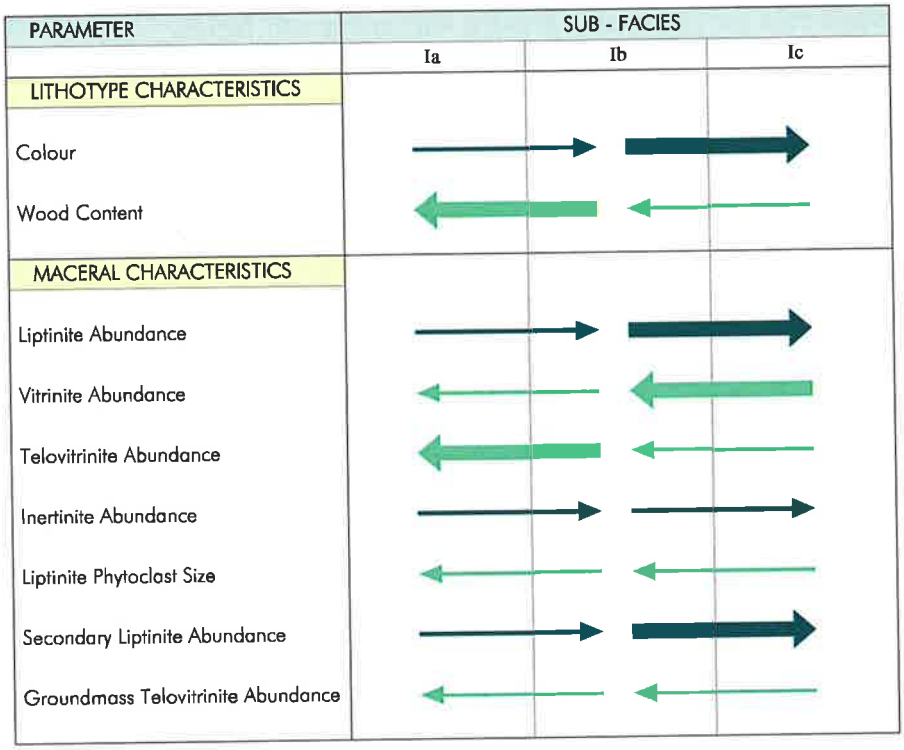
MACERAL VARIATIONS WITHIN FACIES I

Trends from sub-facies Ia to sub-facies Ic include:

a. Increasing liptinite, decreasing vitrinite, increasing inertinite
b. Decreasing telovitrinite
c. Increasing liptinite fragmentation
d. Increasing telovitrinite fragmentation

Increasing secondary liptinite

**Figure 6.2**
**FACIES I MACERAL VARIATIONS**




KEY :
(i) Arrow direction indicates lightening trend (colour), increasing size (liptinite phytoclasts) and increasing abundance (all other parameters).
(ii) Arrow weight indicates shift magnitude.

Figure 6.3 Lithotype and maceral trends in facies I coals

### 6.2.2 Sub-facies Ia

Sub-facies Ia coal is earthy in texture, ranges from medium to light in colour and is characterised by abundant telovitrinite phytoclasts and wood fragments. The latter two constituents, where abundant, readily differentiate this facies. Other diagnostic features are a moderate liptinite content, a terrestrial liptinite assemblage and a low degree of gelification (Figure 6.3, Plates 6.1 and 6.2). MTI for this sub-facies averages approximately 75 and 50 for the Lochiel and Bowmans Deposits, respectively. This coal can be considered to comprise two distinct fractions: groundmass containing assorted vitrinite and liptinite constituents in varying degrees of breakdown (Plate 6.1), and large tissue fragments of telovitrinite (Plate 6.2).

Texture ranges from earthy to moderately fibrous although some variability exists between deposits. A low content of groundmass tissue is typical of Lochiel coals, while slightly higher levels occur in Bowmans coals. Woody fragments are generally dark to reddish brown, occur within a medium (to light) brown groundmass, and were detected up to maximum dimensions of 3 m in length by 0.2 m in diameter (in trial pit exposures). They vary widely in composition, texture, morphology and gelification (see Section 5.2.2) and are typically

aligned parallel to bedding, although in rare instances vertical orientations were observed. Leaf cuticle fragments are commonly present within this sub-facies.

The groundmass has a moderate liptinite content, typically 12-20% and averaging 14.5% of the total coal volume. The distribution, size and preservation of this liptinite show some degree of variability in line with the generally heterogeneous nature of the sub-facies. However, the assemblage is distinctly terrestrial and intact liptinites are dominated by resinite and suberinite (as individual and cell sized fragments and larger associations), with generally minor amounts of cutinite and sporinite. Liptodetrinite typically is the most abundant liptinite maceral, with LPI ranging from 30 to75 (low to moderate) and revealing a slightly better preservation of primary liptinites in the Bowmans Deposit.

The vitrinite-dominated groundmass consists mainly of detrovitrinite and in particular attrinite, with some densinite. Groundmass telovitrinite is low and restricted to small often partially degraded phytoclasts of variable morphology. Gelovitrinite, especially corpogelinite, is ubiquitous although it usually occurs in low abundance. The inertinite fraction occurs in very low concentration (approximately 1%) and is mainly represented by occasional funginite and small inertodetrinite fragments.

Large telovitrinite phytoclasts contrast strongly with the groundmass and display significant variability in cell morphology, nature of inclusions and gelification. Two general forms were recognised, (Plates 5.12 and 6.2; Appendix C). The most common variety is typified by poorly to moderately well gelified phytoclasts, rich in corpogelinite or porigelinite, and is essentially free of liptinite inclusions. Some degree of porosity is evident, cell walls are clearly defined and displays a fresh, well-preserved cellular structure (Plates 6.2b-c,e-g). The second widespread variety of telovitrinite is well gelified with essentially no open pores, contains very fine liptinite inclusions (possibly resinite or bituminite) and its cell walls exhibit evidence of degradation (Plates 5.12, 6.2d). On the macroscopic scale, the former appears to correlate mainly with the large fibrous wood fragments, while the latter is generally associated with the small, elongate, well gelified (possibly subaerial) particles. While both varieties occur throughout sub-facies Ia at Lochiel and Bowmans, the ratio of small, better gelified and liptinite-rich telovitrinite to large, open-celled types is highest in Bowmans coals.

Crystalline mineral matter is more commonly observed in sub-facies Ia coal than in the other types. It occurs as either pyrite within telovitrinite phytoclasts, or fine (to medium) grained detrital quartz disseminated within the groundmass. The latter is most common, but appears restricted to certain plies of sub-facies Ia coal, especially where large fibrous woody material is abundant. Maceral composition appears constant between the low- and high-mineral varieties.

Further differentiation of sub-facies Ia coal may be possible using telovitrinite and wood characteristics in association with other slight maceral changes. For example, the fibrous woody fragments of varying size, shape, gelification and hardness (the porous, liptinite-free telovitrinite, "W3"; see Section 5.2.2) commonly occur in poorly gelified coal where they are associated with a distinctive thick cuticle and may be enriched in detrital mineral. In contrast, smaller, elongate clasts of woody tissue (i.e. the well gelified, liptinite-rich telovitrinite, "W2") typically occurs in coals of slightly higher gelification and are associated with suberinite enrichment. However, the two macroscopically distinctive tissue types are not mutually exclusive and their relative abundance may reflect subtle palaeoenvironmental changes.

### 6.2.3 Sub-facies Ib

Sub-facies Ib coal shares many characteristics with that of sub-facies Ia, most notably the groundmass component, and the two appear closely related. Overall, the abundance of large telovitrinite phytoclasts is significantly less and total liptinite slightly greater than in sub-facies Ia. Macroscopically, these coals are light in colour and characterised by low wood and generally low groundmass tissue contents while microscopically they have a moderate to high liptinite content, a bituminite-poor terrestrial liptinite assemblage and a low telovitrinite content (Figure 6.3; Plate 6.3).

Lithotype features are not especially distinctive with the most significant including a medium, (to light) brown colour, a low wood content and a low to moderate groundmass tissue. Texture typically ranges from earthy to weakly fibrous, although some variability in the relative amount of groundmass tissue is evident between deposits (i.e. higher at Bowmans), resulting in the occasional development of moderately fibrous textures. Furthermore, the groundmass tissue is more variable in this sub-facies at Bowmans where it ranges in size from 0.5 x 2 mm to 1 x 5 mm and consists of black, reddish and light brown particles, compared to the generally smaller and overall darker constituents at Lochiel. Where present, wood clasts are mainly small, elongate fragments, although rare erratically-distributed larger pieces were occasionally noted. Colour overall is possibly slightly darker at Bowmans.

A distinctive terrestrial liptinite assemblage comprising liptodetrinite, suberinite and resinite with minor sporinite and cutinite is characteristic of sub-facies Ib wherein the total liptinite content averages 15%. While the latter is slightly higher than in sub-facies Ia, corresponding with a reduction in large telovitrinite phytoclasts (which typically contain only minor, if any liptinite) their respective liptinite assemblages and concentration within the groundmass are very similar. Liptinite preservation, however, is slightly poorer reflecting the less common occurrence of large (i.e. ≥200 μm) phytoclasts of suberinite, resinite and cutinite. Within sub-facies Ib, liptinite preservation is better at Bowmans (mean LPI =55, cf. 45 at Lochiel).

Liptinite abundance and preservation may vary considerably over short vertical distances, thereby reflecting a degree of microbanding.

The dominant vitrinite fraction is detrovitrinite (averaging ~83%), which in turn comprises mainly attrinite and minor densinite. Gelification is low and appears relatively consistent within and between deposits. Telovitrinite is generally much less abundant than detrovitrinite, and its phytoclasts are mostly small and commonly have a pitted morphology. Vitrinite preservation is almost identical between the two deposits (i.e. VPI ~26), although the proportion of vitrinite in the groundmass of sub-facies Ib is highest at Bowmans. Corpogelinite is widespread, but normally is only a minor constituent.

Inertinite is generally a very minor component (<2% on average) and restricted to occasional funginite and rare inertodetrinite or semifusinite fragments. However, in occasional instances, bands consisting largely of corpogelinite, with funginite and other inertinite particles, do occur (see Section 5.3.6; Appendix C1; Plate 5.13). In these horizons, the concentration of inertinite is elevated significantly relative to the remainder of the coal. Mineral matter is generally not evident in sub-facies Ib.

A rare form of sub-facies Ib coal with a significantly elevated liptinite content was detected in the Bowmans Deposit, suggesting the operation of an atypical mechanism for liptinite concentration. The high liptinite content of this unusual coal is due to abundant syngenetic resinite, which occurs in a variety of forms including resin canals in telovitrinite, isolated cell-sized bodies and larger phytoclasts of no particular morphology. Vitrinite and inertinite components are similar to those in other sub-facies Ib coals. Macroscopically, this variety is light brown in colour.

### 6.2.4 Sub-facies Ic

Sub-facies Ic coal is distinctive and readily identifiable by its characteristic maceral proportions (viz. very high liptinite, low vitrinite and elevated inertinite, especially funginite) and light colour (Figure 6.3; Plate 6.4).

Distinguishing lithotype features include an almost total absence of wood, with the rare occurrences possibly reflecting *in situ* root growth; and a pale yellow brown colour, which is considerably lighter than other varieties. Some degree of mottling by lighter and darker constituents may also be evident. The texture is earthy with limited fine groundmass tissue and, at *in situ* moisture levels, the coal tends to be considerably harder than other types. In rare instances, enrichment in detrital mineral may occur.

The maceral composition of sub-facies Ic coal is distinctly different from that of any other variety in the Lochiel and Bowmans suite and is characterised by a very high liptinite content (mean ~55%). An assemblage of mainly small terrestrial liptinites, principally resinite, suberinite, sporinite and some cutinite, combined with abundant liptodetrinite occurs within a bituminitic groundmass. The size of intact liptinite phytoclasts is variable, but mostly less than 50 μm, although larger cutinite fragments also occur. The latter appears to be the dominant liptinite where sub-facies Ic horizons overlie, or occur in close stratigraphic proximity to, sub-facies Ia coals rich in large fragments of fibrous wood. Conversely suberinite dominates where elongate, well-gelified tissue constitutes the main woody component. Resolution of discrete liptinite grains is difficult where they appear partly fused into the bituminitic groundmass. Some variability is evident in liptinite abundance (from almost exclusively liptinite, to abundant liptinite with vitrinite) and is possibly indicative of microbanding. Key characteristics such as total liptinite content and bituminite content are lower at Bowmans (means: 28% and 1%, respectively) than at Lochiel (means: 60% and 10%, respectively).

Vitrinite is significantly less abundant than in other coal facies, averaging ~41% and comprising almost entirely detrovitrinite. Telovitrinite is rare and consists of small phytoclasts (typically 20-50 μm), showing pitted and rough edges. Less common larger phytoclasts possibly correspond to the macroscopically visible root material. Some corpogelinite bodies (typically ~20 μm diameter) occur and show a pitted surface texture, similar to the smaller telovitrinite phytoclasts. Inertinite abundance, although low (~4%), is clearly elevated relative to the other facies. Its inertodetrinite and funginite components both appear relatively evenly distributed. Other inertinites include rounded bodies, possibly altered corpogelinite, and small fusinite phytoclasts.

Gelification appears low, although its precise assessment is hindered by the very low vitrinite content of this sub-facies. Individual vitrinite gains may be entirely surrounded by liptinite, resulting in low GI values based on the standard criteria for gelification assessment. However, the apparent fusing of liptinite fragments within the bituminite groundmass results in an analogous consolidation of the organic constituents. Although this effect cannot be quantified, it may be responsible for the apparent hardness of sub-facies Ic coals.

## 6.3 FACIES II

### 6.3.1 General characteristics and definition of sub-facies

In both their lithotype and maceral characteristics, facies II coals differ from those of facies I. Macroscopically they are darker, poorer in wood and generally richer in dark, platy tissue. Their distinguishing micropetrographic characteristics include: a higher content of groundmass telovitrinite (typically present as elongate phytoclasts), a lower content of massive telovitrinite, a higher ratio of aquatic to terrestrial liptinite (commonly dominated by fine cutinite), and a higher degree of vitrinite groundmass tissue and liptinite preservation (Figure 6.4). In addition, their liptinite content is generally much lower, their vitrinite gelification is higher, and their inertinite content (especially fusinite) can be considerably elevated. Gelification is well advanced in both the detrovitrinite and telovitrinite components. In contrast to facies I, however, the extent of telovitrinite gelification generally matches or exceeds, that within the detrovitrinite fraction. The development of micro- (and macro-) banding by groundmass telovitrinite, fusinite and cutinite also differentiates facies II coals from other varieties, especially those in facies I.

Relatively subtle changes in gelification, liptinite content and inertinite abundance were used to define two sub-facies. Sub-facies IIa appears somewhat transitional to facies I, especially in its liptinite assemblage, while sub-facies IIb is more distinctive, containing abundant groundmass telovitrinite, greater inertinite and a tendency toward an aquatic-dominated liptinite assemblage (Figures 6.5 and 6.6).

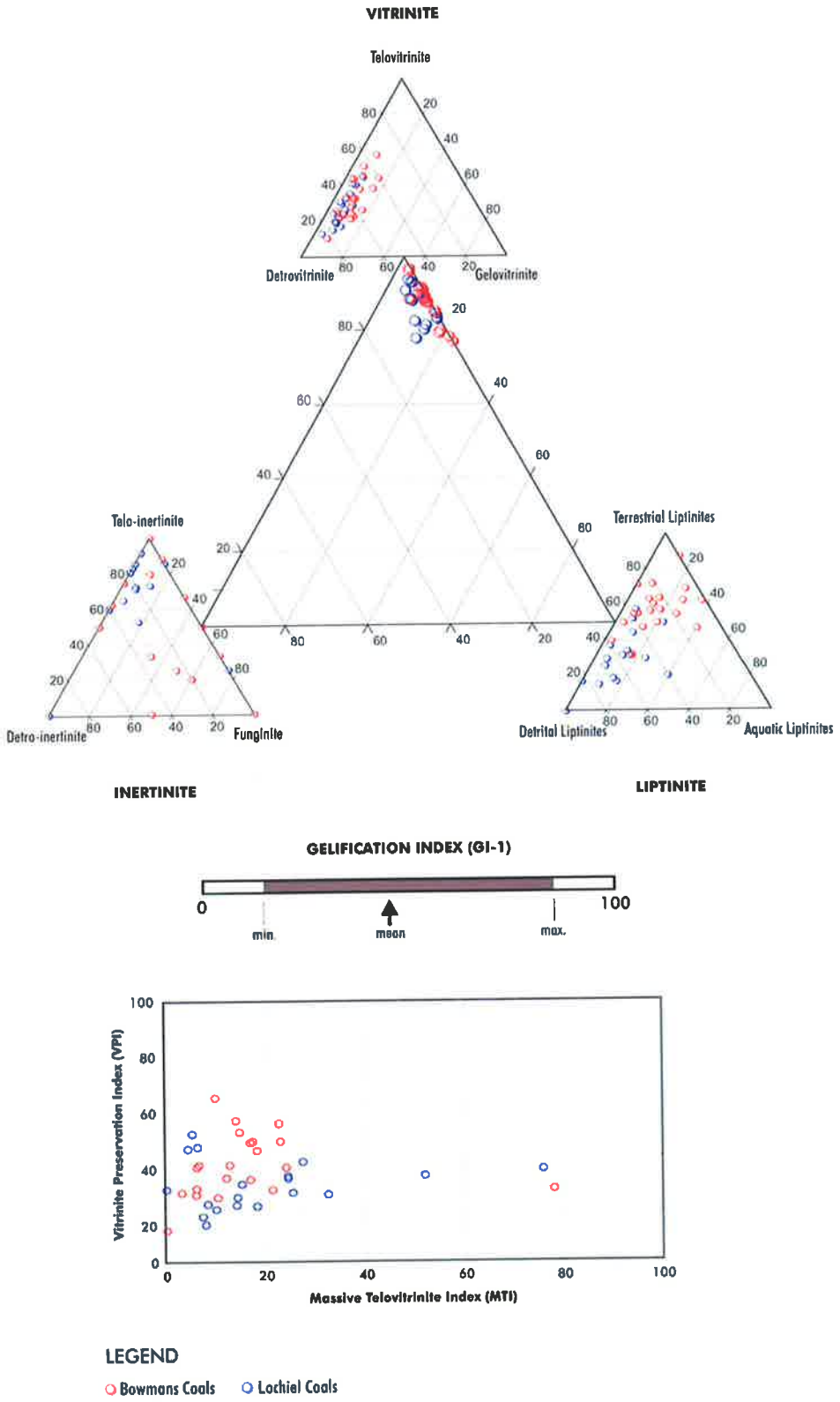
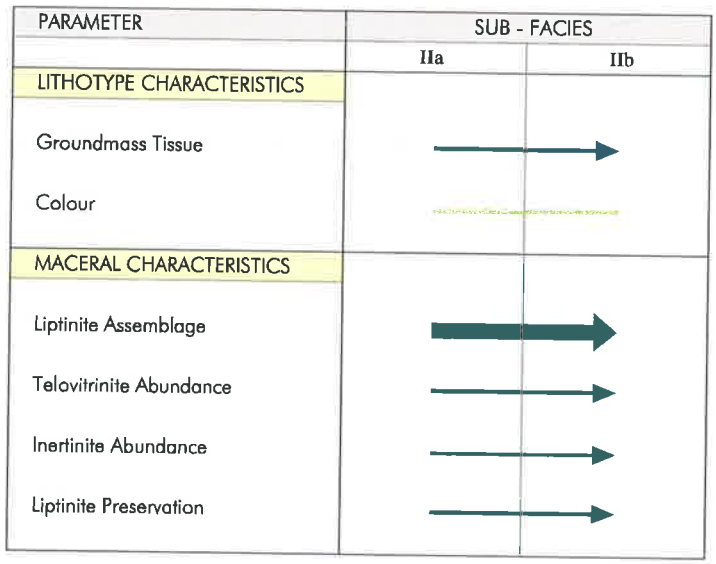



Figure 6.4 Maceral characteristics of facies II coals




KEY :
(i) Arrow direction indicates increasingly aquatic liptinites (liptinite assemblage), increasing preservation (liptinite preservation) and increasing abundance (all other parameters).
(ii) Arrow weight indicates shift magnitude.
(ii) No direction in colour arrow indicates no discernable difference between sub-facies.

Figure 6.5 Lithotype and maceral trends in facies II coals

### 6.3.2 Sub-facies IIa

#### 6.3.2.1 Common characteristics

Sub-facies IIa coals are transitional between those of facies I and sub-facies IIb. They differ from the latter in their higher ratio of terrestrial to aquatic liptinites, slightly lower abundances of groundmass telovitrinite and inertinite, and somewhat lesser degrees of gelification and liptinite preservation.

Sub-facies IIa coals are dark in colour. Their macroscopic features (notably tissue content, size and composition) vary considerably, thereby hindering lithotype definition, especially in the Bowmans Deposit. Texture ranges from moderately fibrous to fibrous, with variable amounts of platy tissue ranging in size from <1 mm to 5 x 20 mm, aligned parallel to bedding. In some varieties, rectangular and broadly triangular leaf fragments are common and rare charcoal plates occur. Wood content is low and restricted to the elongate, well-gelified forms (1-5 mm x 15-20 mm), rod-like fragments (1-2 mm in diameter) and vertical bands of very highly gelified tissue (2-5 mm thick) possibly representing root material.

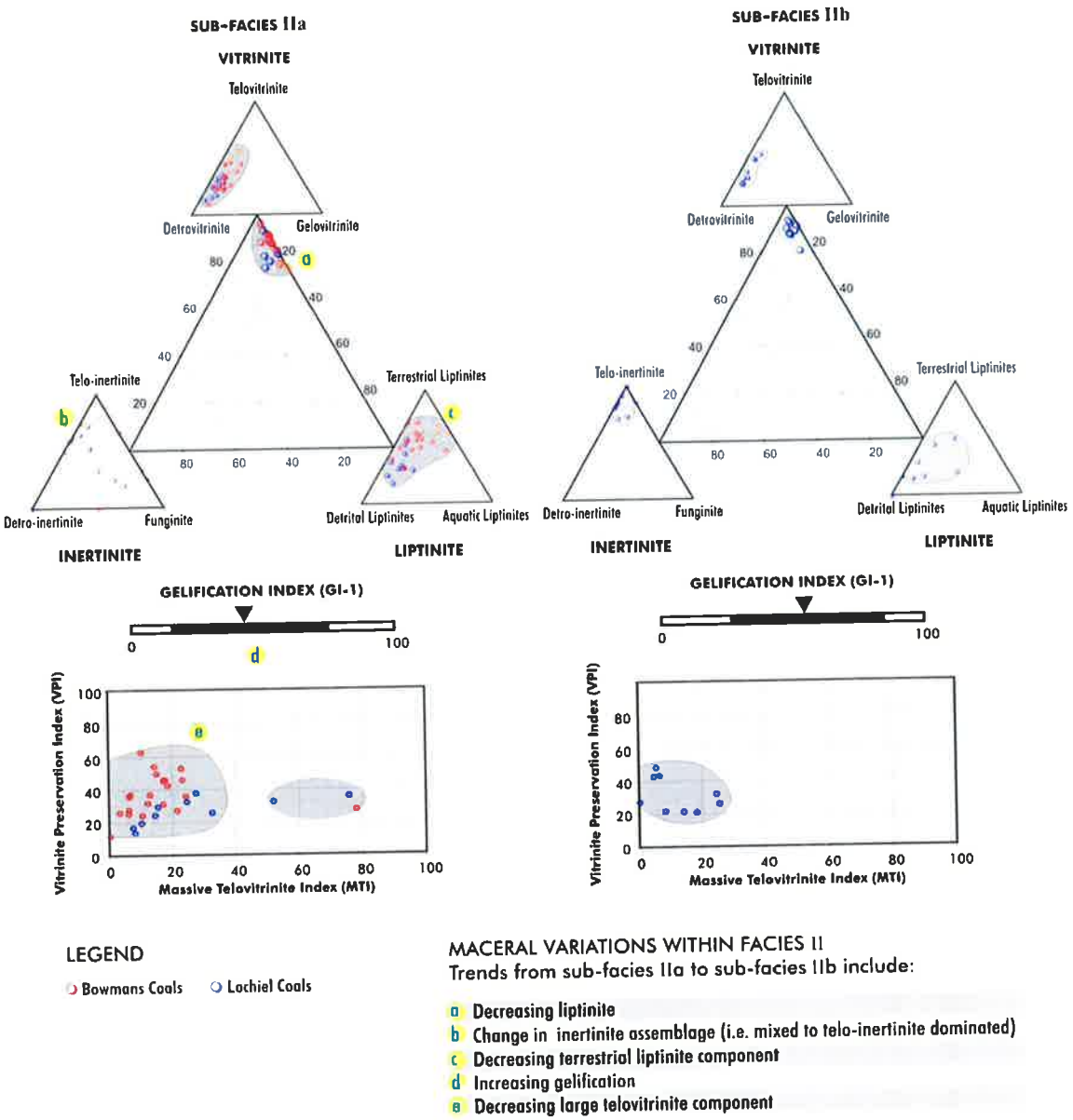



Figure 6.6 Maceral variations within facies II coals

The maceral assemblage of this sub-facies is dominated by vitrinite (averaging 87%) and, in particular, densinite (Plate 6.5). Phytoclasts of groundmass telovitrinite are common (averaging 23%) and occur in a variety of sizes and shapes. While no particular morphology is dominant, thin well-gelified, elongate varieties (20-50 μm x several 100 μm) are widespread. Telovitrinite phytoclasts also vary in appearance, from intact cellular associations with distinct boundaries to those showing evidence of considerable fragmentation, with the latter possibly predominating. Furthermore, intervals dominated by multiple telovitrinite bodies with limited amounts of intervening detrovitrinite (possibly reflecting partial cell breakdown, followed by regelification) were noted. Large (i.e. non groundmass) telovitrinite phytoclasts are rare and represented by well-gelified forms showing partial cell breakdown and fine liptinite inclusions. Gelification is moderate (to high), with

increased levels evident in the tissue-rich intervals, and is relatively even across the detrovitrinite and telovitrinite fractions.

The liptinite content of sub-facies IIa is moderate to low (averaging 12%) and contains a mixed and variable assemblage of terrestrial and aquatic components, generally represented by suberinite and thin cutinite, respectively. Thc latter is occasionally observed attached to elongate telovitrinite phytoclasts. Liptinite preservation is moderate (LPI = 55 and 60 for the Lochiel and Bowmans Deposits, respectively) and higher than in facies I coals. Overall, inertinite is of very low abundance (averaging 1.5%), although rare large fusinite phytoclasts are present.

### 6.3.2.2 Sub-facies IIa varieties

Slight variations of texture, tissue preservation and liptinite characteristics within sub-facies IIa coals facilitated the definition of three varieties (Figure 6.7; Table 6.3). One is restricted to Lochiel where it is relatively widespread, while the other two are recognised only at Bowmans and are uncommon. Those from Bowmans show consistently better tissue preservation.

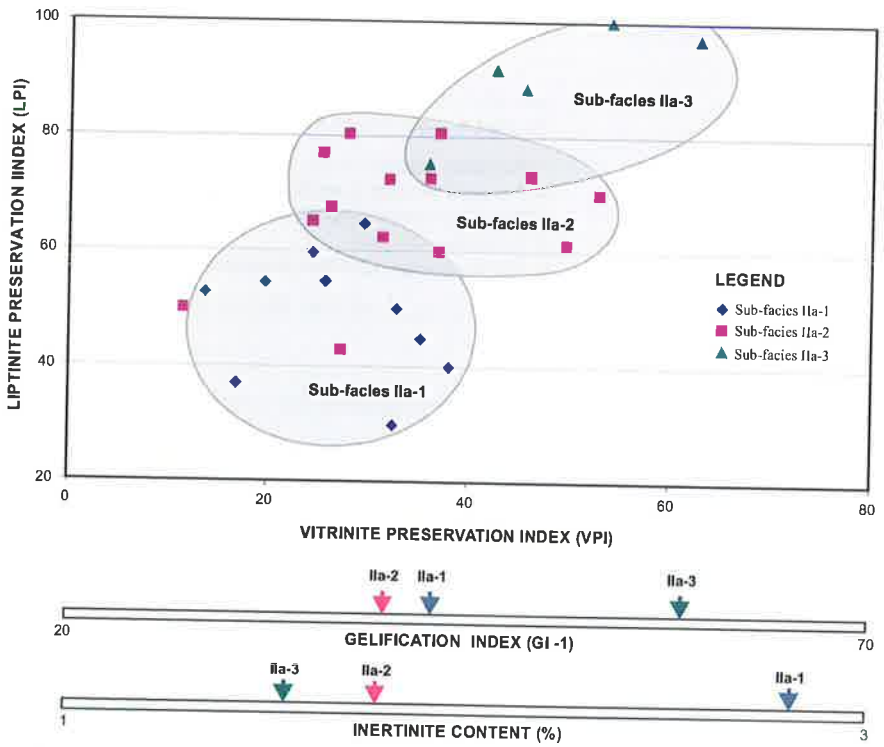



Figure 6.7 Petrographic characteristics of sub-facies IIa varieties

Table 6.3 Key petrographic characteristics of the sub-facies IIa varieties

| Parameter | Sub-facies IIa-1 | Sub-facies IIa-2 | Sub-facies IIa-3 |
|---|---|---|---|
| Liptodetrinite | 5.9 | 3.2 | 1.9 |
| Total liptinite | 11.9 | 10.2 | 15.1 |
| Total inertinite | 2.7 | 1.2 | 0.8 |
| Vitrinite preservation (VPI) | 26.9 | 34.0 | 48.1 |
| Liptinite preservation (LPI) | 48.8 | 67.3 | 90.5 |
| Gelification index (GI-1) | 39.8 | 36.5 | 61.0 |

Sub-facies IIa-1 occurs only in the Lochiel Deposit and is represented by an essentially wood-free, groundmass telovitrinite-rich, liptinite- poor coal, with a moderately fibrous to fibrous texture. Groundmass tissue is mostly dark, ranging from 2 x 5 mm to 5 x 20 mm in size and consisting of rectangular and leaf like forms, with rare charcoal (i.e. fusinite) plates. The liptinite assemblage is a mixture of terrestrial and aquatic components.

Of the Bowmans varieties, sub-facies IIa-2 displays the general features of sub-facies IIa-1, but with slightly less groundmass tissue, leading to a moderately fibrous texture, and increased amounts of lighter, probably cuticular and periderm-sourced tissue. Gelovitrinite is also possibly slightly more abundant and a corpogelinite-dominated groundmass texture occurs in rare instances. The liptinite fraction is mostly of terrestrial origin, with suberinite the main constituent. The remaining Bowmans variety (sub-facies IIa-3) exhibits a very fibrous texture caused by abundant dark-, light- and reddish-brown groundmass tissue, and which results in a corky appearance. Large well-preserved liptinite phytoclasts of suberinite, resinite and cutinite are present, along with only minor liptodetrinite. In addition, moderate to large phytoclasts of groundmass telovitrinite occur giving rise to well-defined banding. This coal also exhibits higher gelification than the other sub-facies IIa varieties and may include fine detrital mineral matter.

### 6.3.3 Sub-facies IIb

Sub-facies IIb is restricted to the Lochiel Deposit where it is represented by a well-gelified coal rich in groundmass telovitrinite but poor in both wood and liptinite (Figures 6.4 and 6.6; Plate 6.6). Its mostly aquatic liptinite assemblage and increased levels of fusinite and groundmass telovitrinite distinguish it from sub-facies IIa. Better tissue preservation and a lower total liptinite content also assist its differentiation.

Sub-facies IIb coals are macroscopically distinctive and form excellent marker bands (see Section 7.2.5). Texture typically ranges from fibrous to very fibrous reflecting the presence of abundant dark, platy groundmass tissue, aligned parallel to bedding. This tissue consists of charcoal plates of various sizes (ranging from 1 x 4 mm to 3 x 10 mm), soft, needle-like fragments (from 0.5 x 1 mm to 1 x 3 mm) and platy remnants showing a distinct leaf-like

morphology (commonly from 2 x 15 mm to 5 x 20 mm in size). The amount, size and composition of groundmass tissue can vary considerably over narrow vertical intervals. Other macroscopic features include a uniform dark colouration, very low wood content (with the rare occurrences being restricted to small combusted fragments) and a gritty consistency in line with the elevated charcoal content.

Vitrinite is the dominant maceral group (~90%) and densinite its most abundant component, although groundmass telovitrinite including eu-ulminite and texto-ulminite are also common. Telovitrinite occurs as well-gelified, elongate phytoclasts (of the order of 5-20 μm x 50-250+ μm; Plate 6.6a, e and g), commonly with small decentralised cell lumens (~10 μm across), to which fine cutinite may be attached (Plate 6.6f). Multiple telovitrinite phytoclasts can occur in close proximity, with only minimal intervening detrovitrinite. Furthermore, much of the detrovitrinite appears to be derived by partial fragmentation and regelification of this tissue, hindering precise differentiation between detrovitrinite and telovitrinite. Gelification is high and consistent between the detrovitrinite and telovitrinite fractions.

Liptinite abundance is low (viz. ~7%). With only minor terrestrial components, the assemblage is less diverse than that of sub-facies IIa. Thin cutinite, usually attached to telovitrinite phytoclasts, is the dominant and best-preserved liptinite. Palaeobotanical examination of this coal by Rowett (1992) revealed a generally monospecific cuticular composition. Sporinite can be widespread but occurs in low abundance. Tentatively identified bituminitic zones are rare, and resinite and suberinite are generally absent. Liptinite-free zones develop locally where the coal is composed entirely of intact and partially fragmented telovitrinite phytoclasts. The preservation of fine cutinite phytoclasts parallels high tissue preservation within the vitrinite fraction.

Large, irregularly distributed fusinite bodies and finer more evenly dispersed inertodetrinite are distinctive features of this sub-facies. The former are the microscopic expression of charcoal fragments which dominate the groundmass tissue. These fusinite phytoclasts display thin, frequently fractured cell walls, commonly exceed 1000 μm in size and typically highly porous. The latter leads to a lower quantitative measure of fusinite content than the impression gained from qualitative examination. Well-gelified fusinite and funginite also have been detected, but are rare. Inertinite abundance averages 3.5% which, while low, represents a significant increase over the levels encountered within most other Lochiel and Bowmans coals.

## 6.4 FACIES III

Facies III coals are characterised by a uniformly high abundance of detrovitrinite, mostly desmocollinite and densinite, and a high to very high degree of gelification (Plates 6.7 and 6.8; Figure 6.8). Liptinite abundance is low (to moderate) and the assemblage includes aquatic and secondary components such as telalginite and fluorinite. Inertinite is the least abundant maceral group, whereas the concentration of detrital mineral matter is higher than in other facies. Facies III coals also have a variety of characteristics that are typical of sapropelic coals, including a relatively uniform, fine particle size, microstratification and a homogenous texture (Ward, 1984; Diessel, 1992; Taylor *et al.*, 1998).

Macroscopically facies III coals are very dark, soft, wood-free and well gelified, and commonly show a conchoidal fracture pattern. Their texture is most frequently very earthy, with minor groundmass tissue resulting in a homogenous appearance. In some instances, however, small fragments of tissue occur in moderate concentration. Wood is generally absent, with larger tissue fragments being restricted to rare root material. Near-vertical joints are well developed in this facies, in contrast to other coals where jointing is absent, or widely spaced.

The most distinctive micropetrographic feature of facies III coals is their high to very high and uniform gelification (especially within the dominant detrovitrinite fraction). Their content of total vitrinite is uniformly very high, averaging 88%. Telovitrinite abundance is variable (although generally low to very low) and large phytoclasts are rare. Telovitrinite gelification is somewhat heterogeneous, with the smaller, strongly elongate phytoclasts showing the highest levels.

Total liptinite abundance varies from low to moderate (8-14%, averaging 10.5%). The constituent maceral assemblage is unique, with alginite and fluorinite being restricted to this facies (Plates 6.7 and 6.8). Cutinite, displaying a variety of morphologies and in some instances attached to telovitrinite phytoclasts, generally represents the dominant intact liptinite. Fluorinite occurs as small (~5 μm) rounded bodies and, while concentrated in particular zones, appears to be irregularly distributed. Alginite is more evenly distributed throughout the groundmass. Other liptinites, including resinite, suberinite and sporinite (some of it highly ornamented), are widespread but represent minor constituents. Liptodetrinite is generally finely fragmented (<1 μm) and varies widely in relative abundance, from rare to being the dominant component. Consequently, the LPI of facies III coals has a wide range and on average is lower than for all but sub-facies Ic (Table 6.2).

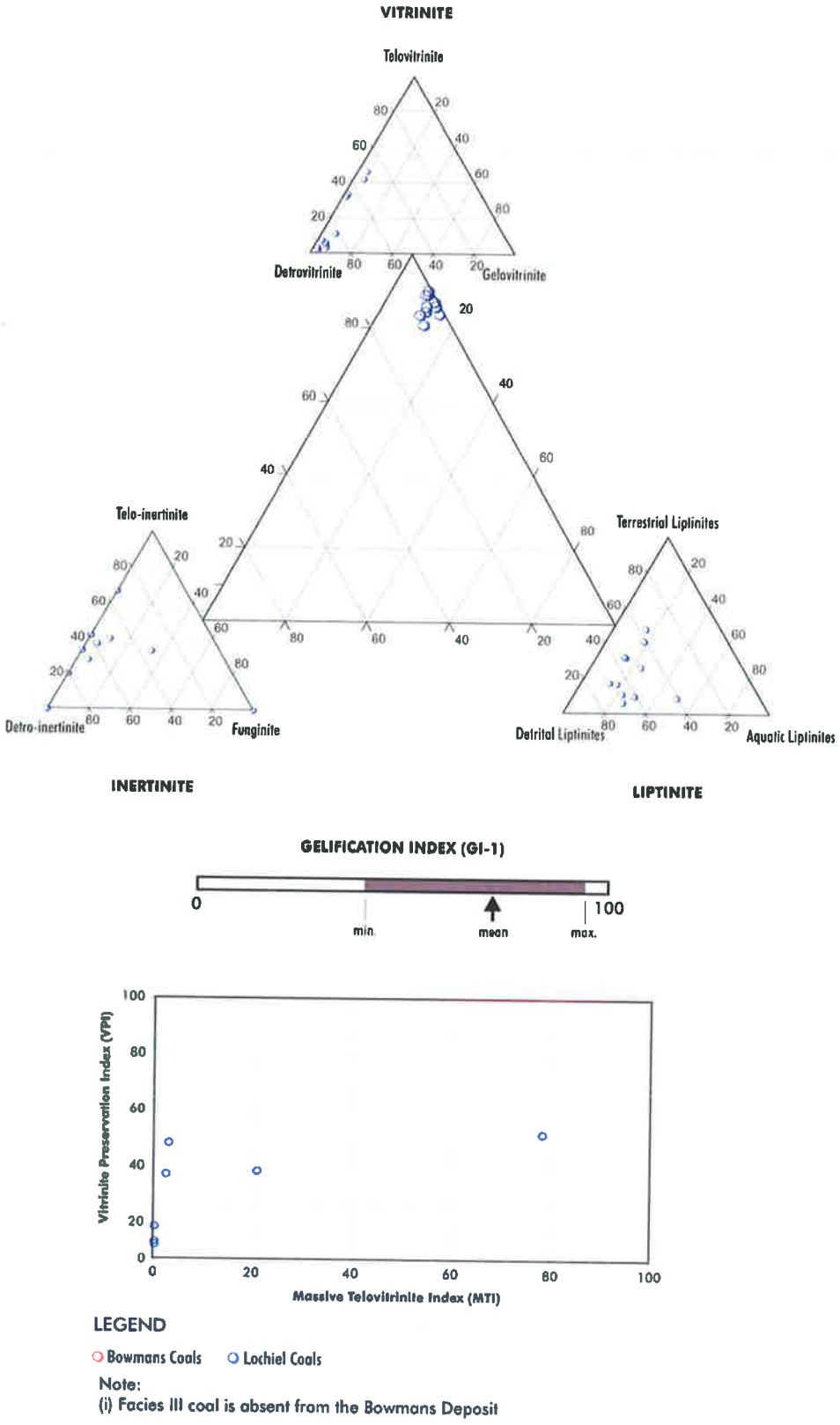



Figure 6.8 Maceral characteristics of facies III coals

Inertinite is the least abundant maceral group, averaging ~1% and comprising mainly small, well disseminated inertodetrinite and rare fusinite. Elongate phytoclasts, including cutinite and where present telovitrinite, together with assorted other liptinites, commonly form a well-defined microstratification.

Based on the abundance of mineral matter, two varieties of facies III can be recognised, although the maceral composition of both is similar and insufficient for formal division into sub-facies (Plates 6.7 and 6.8). The mineral-rich variety shows slight departures in lithotype characteristics such as colour (i.e. tendency toward dull grey black) and the presence in low concentration of evenly disseminated light coloured mineral inclusions (up to 1 mm in size). It also has a uniformly low telovitrinite content, a more variable degree of gelification, and a higher proportion of inertinite, including large phytoclasts of fusinite and macrinite.

## 6.5 FACIES IV

Facies IV coals differ substantially from those in other facies in that their physical and maceral properties show clear evidence of alteration. Two distinct varieties are recognised (sub-facies IVa and IVb). The former is rich in inertinite, while the latter has undergone mainly physical modification (Table 6.4). Specific maceral properties vary with the primary coal type from which they are derived.

Table 6.4 Petrographic variations within facies IV

| Parameter | Sub-facies IVa | Sub-facies IVb |
|---|---|---|
| LITHOTYPE | | |
| Appearance | Fragmented/nodular | Fractured |
| Colour | Dark | Mottled (medium – dark) |
| Hardness | Very hard | Soft and friable |
| MACERAL COMPOSITION | | |
| Total vitrinite | 36.3 | * |
| Total liptinite | 3.3 | # |
| Total inertinite | 60.3 | * |

Key: * Maceral properties indistinguishable from the primary coal type
# Possibly slightly increased over level in primary coal

### 6.5.1 Sub-facies IVa

Sub-facies IVa coal is characterised by a high content of inertinite, in particular macrinite (Figure 6.9; Plate 6.9), which is derived from strongly decomposed and gelified peat particles that have subsequently been fusainised (ICCP, 1975; Scott, 2002). High macrinite levels are restricted to this sub-facies, but they fluctuate widely between 20 and 100%.

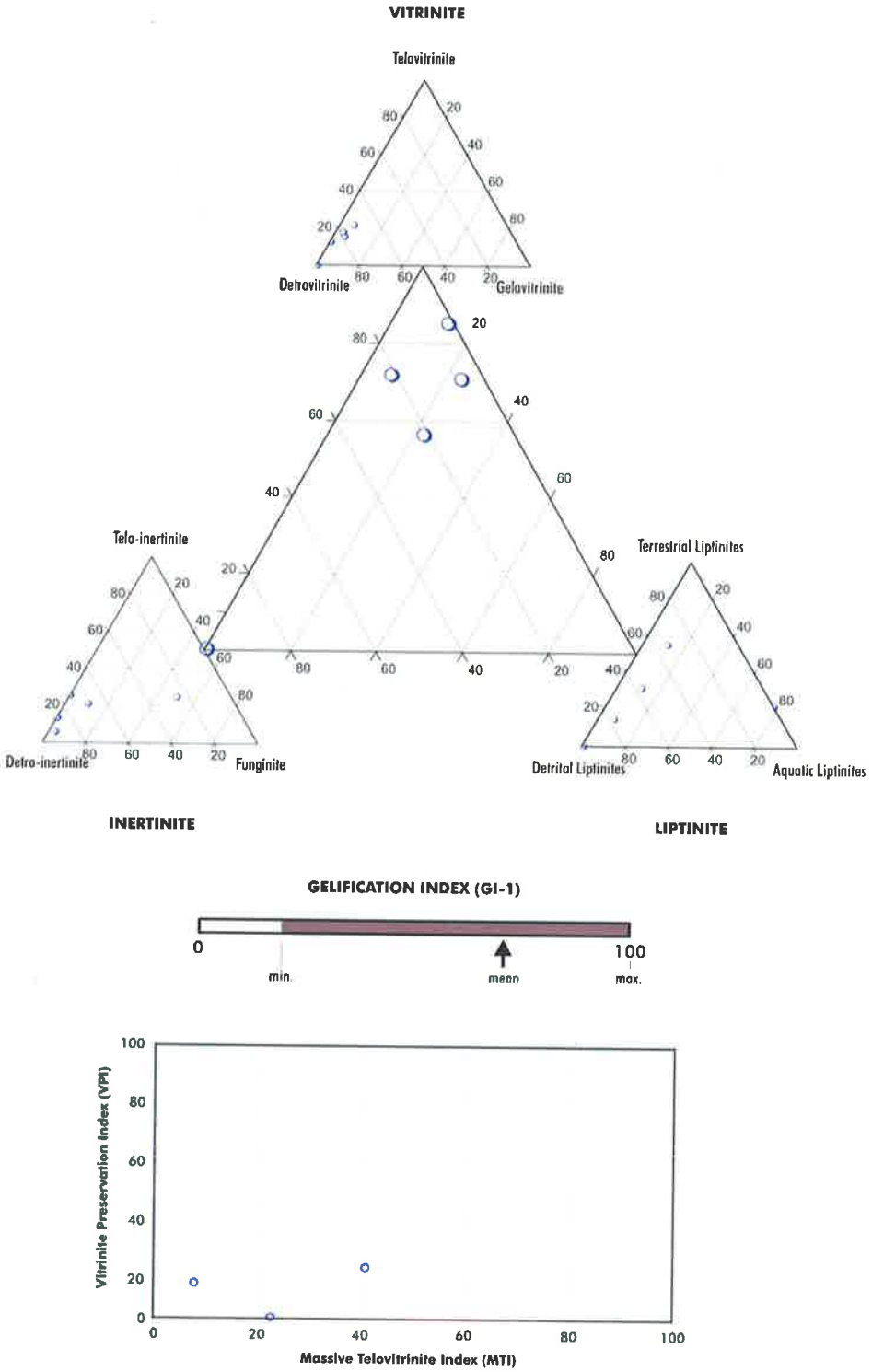



Figure 6.9 Maceral characteristics of facies IV coals

Macroscopically, plies of sub-facies IVa coal commonly are highly fragmented (brecciated) and consist of hard, dark, angular and brittle gravel-sized particles 1-30 mm in size, sometimes within a silty matrix. Individual fragments can be friable and vesicular, or alternatively may adopt a nodular habit wherein a number of particles appear weakly cemented and, in some cases, pyritised. A less common mode of occurrence is represented by thin horizons of hard, discrete nodules (0.02-0.05 m) within a matrix of fresh coal. In both forms the original macrotexture is obscured.

Microscopically, sub-facies IVa coal is readily distinguished by its high macrinite content. The reflectivity of this macrinite is not uniform, suggesting varying degrees of alteration. Rare individual gains have oxidation rims, such that their reflectance decreases inward from their margins. Inertinites other than macrinite generally occur in low relative abundance, although that of fusinite can be significant while the contents of vitrinite and liptinite vary inversely with macrinite abundance.

Although oxidised, the original microtexture is well preserved and many primary components can be recognised. In the most strongly affected portions, liptinites appear to have been volatilised, leaving small voids in the groundmass, although with lesser oxidation they remain, but with significantly reduced fluorescence intensity. Clastic mineral matter and pyrite identified macroscopically are also evident, with the former occurring as discrete grains and infillings within larger pores, while the latter commonly occurs as veins and nodules. Sub-facies IVa coal appears to have been derived mainly from facies III and, to a lesser extent, facies II coals.

### 6.5.2 Sub-facies IVb

Sub-facies IVb coal is characteristically soft and friable, and somewhat mottled (from very dark to medium brown) and distinctly fractured in appearance. Although in places discernable, the original groundmass texture is more typically obscured.

No definitive changes to the maceral characteristics of the original coal were detected in this sub-facies. However, there is possibly a slight decrease in gelification; elevation of the liptinite content; and increased pitting of corpogelinite and, to a lesser extent, telovitrinite, although these changes do not necessarily occur uniformly. For example, discrete grains (or parts thereof) may be extremely rich in liptinite (i.e. approaching the levels detected in sub-facies Ic), but these co-exist with zones of much lower abundance. Transitions between these zones are inconsistent and vary from sharp to gradational. It is noteworthy that the zones very rich in liptinite differ from those in sub-facies Ic in that the bituminitic groundmass is absent and the contents of funginite and intertodetrinite are not elevated. The liptinite-rich and liptinite-poor zones possibly equate to the lighter and dark mottled portions of the coal that

are visible macroscopically. Gelification also appears to vary substantially, with poorly- and well-gelified zones co-existing within and between grains.

## 6.6 LIKELY DEPOSITIONAL SETTINGS OF THE COAL FACIES

A wide spectrum of local coal-forming palaeoenvironments are postulated to have existed in the northern St. Vincent Basin. Facies I to III are interpreted as primary coal types reflecting changing groundwater levels, vegetation and biomechanical conditions (Figures 6.10 and 6.11) while facies IV coals are though to have undergone some degree of alteration following peat accumulation (Figure 6.12). Sub-facies are considered to reflect either differing levels of biochemical modification of an essentially similar peat, or slight changes in the nature of organic input.

### 6.6.1 Facies I

#### 6.6.1.1 Primary Environment

A terrestrial environment in which the peat accumulated largely from autochthonous forest vegetation is inferred for facies I. Precise groundwater conditions are difficult to quantify and may have ranged from topogenous settings including shallow permanent standing water, through alternating exposed and inundated environments, to at times ombrogenous settings. However, the environment appears to have permitted growth of a wide variety of gymnosperm and angiosperm taxa, ranging from large trees to smaller understory plants.

Facies I coals are closely associated with terrestrial constituents such as resinite, suberinite and wood fragments, and display a low degree of gelification. Considerable compositional variations exist and are particularly evident in the woody fraction, possibly reflecting the lateral coexistence of some of the numerous palaeobotanical assemblages identified in the Mid Tertiary of Southern Australia (Manuel, 1988; Christophel, 1989; Rowett, 1992; Stoian, 2003). However, the abundant wood-derived biomass (which is best preserved in sub-facies Ia), suggests that the environment hosted large-scale production of vegetable matter.

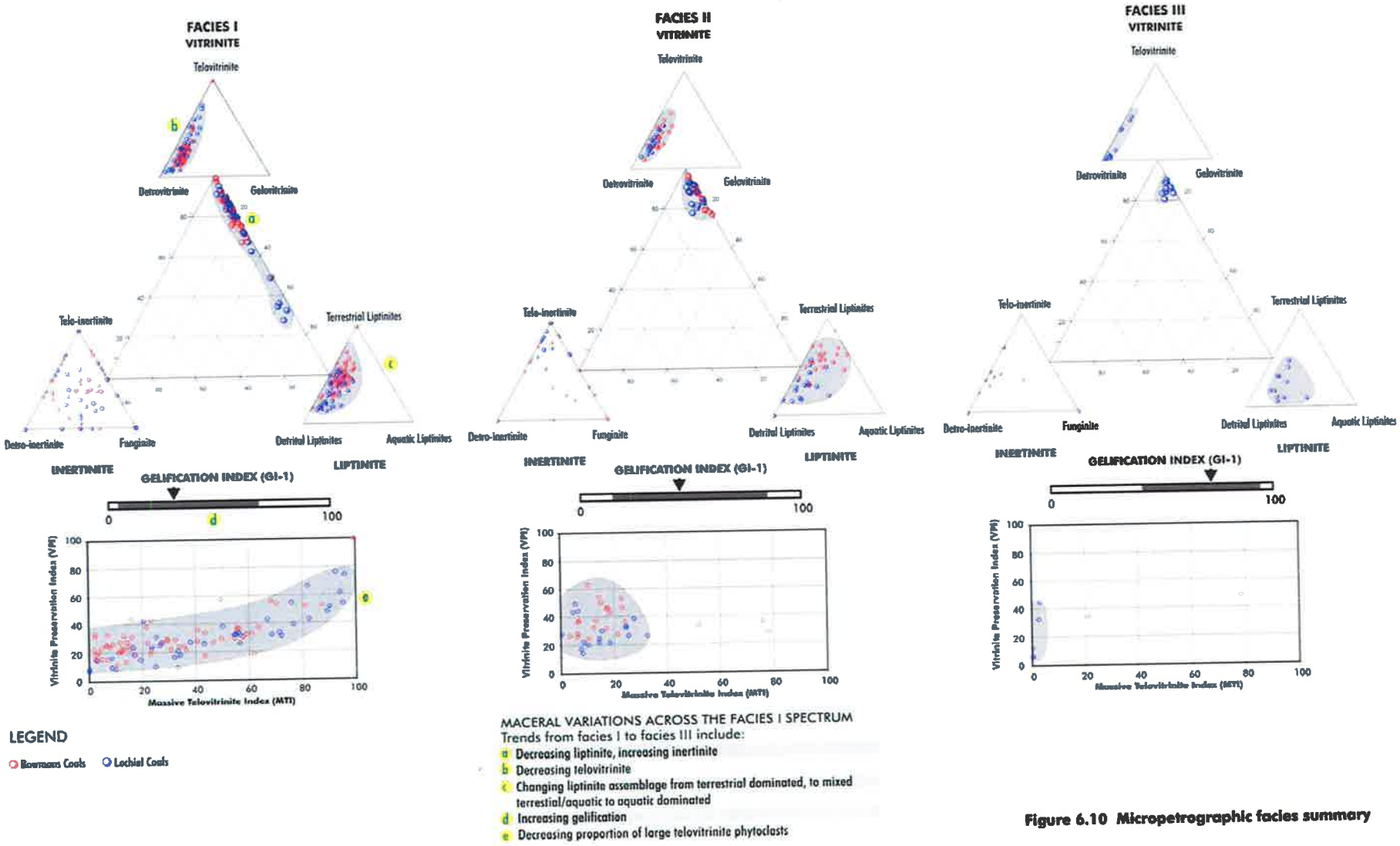
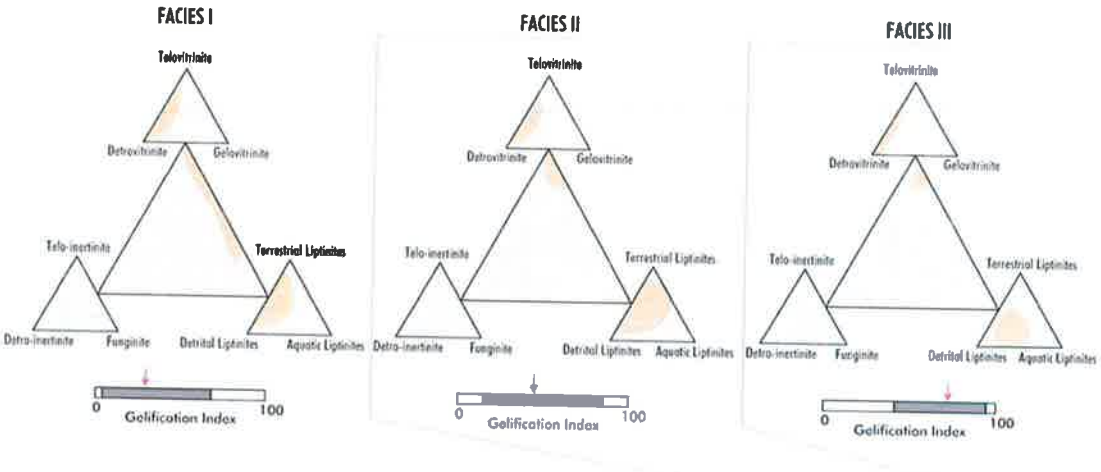
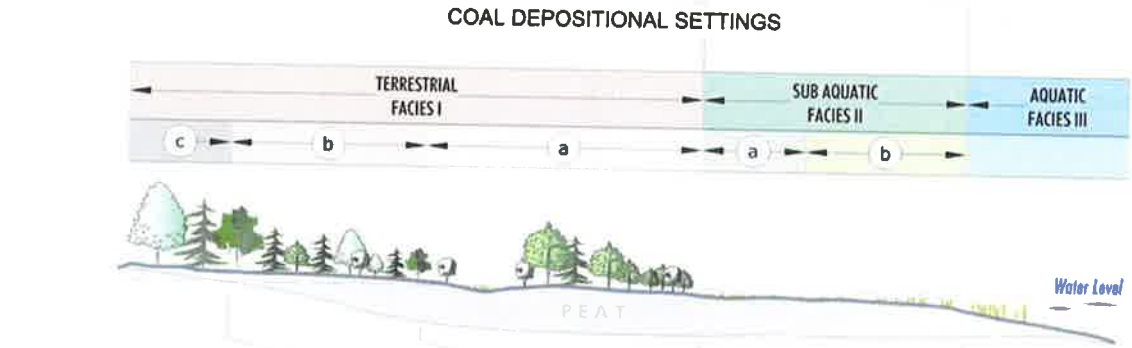



**Figure 6.10 Micropetrographic facies summary**




| | | | | | |
|---|---|---|---|---|---|
| WATER COVER | None | Ombrogenous / oscillating | Oscillating | Complete | Complete - open water |
| ATMOSPHERIC $O_2$ | Present | Partially present | Partially present (to limited) | Limited | Very low- absent |
| ORGANIC ACTIVITY | Fungi, aerobic bacteria | Aerobic and anaerobic bacteria | Aerobic and anaerobic bacteria | Mainly anaerobic bacteria | Anaerobic bacteria |
| PEAT PRODUCTION | Low | Moderate (to high) | High | Moderate | Low |
| ORGANIC AND MINERAL INPUT | Forest vegetation of mixed Gymnosperm and Angiosperm species. Limited mineral except for occasional overbank incursion. | | | Small water tolerant species. (Possibly angiosperm and marsh vegetation). Limited mineral input. | Fine detrital material and aquatic detritus. Fine sediment common. |
| COAL TYPES | Extreme Liptnite enrichment. Low gelification and low tissue preservation. Terrestrial liptnites. Earthy, pale | Low gelification and low tissue preservation. Terrestrial liptnites. Earthy, low wood. | Low gelification and high tissue preservation. Terrestrial liptnites. Wood rich, earthy. | Moderate gelification Mod - high tissue preservation. Mixed liptnite assemblage. Firbous, dark. | Moderate - high gelification. Moderate - high tissue preservation. Mostly aquatic liptinites. Very fibrous, dark, occasional charcoal plates. | Very high gelification. Low tissue preservation. Aquatic liptnites, homogenous, dark, very earthy. |

INCREASING BIOMECHANICAL DEGRADATION OVER FACIES I

INCREASING TERRESTRIAL INPUT OVER FACIES II

Figure 6.11 Interpreted palaeoenvironments of the coal facies

Assorted palaeobotanical studies of northern St. Vincent Basin coals, commonly based on wood rich facies I varieties, indicate closed, mixed angiosperm/gymnosperm forests were widespread over the region. Among the fossil plants identified are examples of the gymnosperm families *Podocarpaceae* and *Araucariaceae* and of the angiosperm families *Myrtaceae* and *Proteaceae* (Meakin, 1985; Manuel, 1988; Rowett, 1992; Rowett and Stoian, 1999; Stoian, 2003). More specifically, from his evaluation of fossil wood, Manuel (1988) identified a gymnosperm-dominated assemblage with features characteristic of the *Podocarpaceae*. The subordinate angiosperm inputs included *Myrtaceae*, with lesser contributions from *Proteaceae* and *Araliaceae*. In contrast, the palynological assessment of Stoian (2003) suggests that angiosperms were typically several times more abundant than gymnosperms. Rowett's (1992) evaluation of dispersed cuticle revealed a large and diverse floral assemblage dominated by *Araucariaceae*, with significant contributions from *Podocarpaceae*, *Proteaceae* and *Myrtaceae* and minor inputs by *Casuarinaceae*, *Elaeocarpaceae*, *Lauraceae* and *Zamiaceae*. Manuel (1988) used vessel diameter and density to infer that the angiosperms were predominantly small trees and shrubs, with Meakin (1985) suggesting that they may have formed the forest understory.

The significance of a gymnosperm dominance based on fossil wood occurrence is uncertain. The distribution and abundance of gymnosperm wood may be a function of its greater resistance to decay and hence better preservation, relative to the angiosperms, as noted by Kolcon and Sachsenhofe (1999) and Bectel *et al.* (2003). These authors suggested that, in some coals, gymnosperms may constitute all the macroscopic wood and, hence, that tissue preservation may be governed by the primary proportion of gymnosperms in the original peat. However, numerous local assemblages and sub-environments of gymnosperms and angiosperms are likely to have developed in response to subtle changes in groundwater conditions and detailed palaeobotanical interpretation is beyond the scope of the present study. Importantly, all the available palaeobotanical data support the inference of a terrestrial forest environment for facies I.

The near absence of fusinite from facies I coals is significant and suggests continuously wet conditions, which may have been assisted by the tree canopy providing protection against desiccation and combustion. In addition, the introduction of allochthonous fusinite may have been limited by a generally low groundwater table and, at times, ombrogenous settings (permitting only aeolian transport), and/or a lack of proximal fusinite-producing settings. Primary productivity and the rate of biomass accumulation are likely to have been high in this setting, helping to minimise the relative proportion of allochthonous fusinite.

Variable amounts of disseminated fine to medium sand, although not typical of this facies, can occur within its coals, indicating a degree of overbank incursion and raising the possibility of an allochthonous organic component. However, the existence of petrographically identical, essentially mineral-free varieties suggests accumulation near the

living position of most of its precursor vegetation. High tissue preservation in mineral-rich coals may reflect rapid burial and/or increased nutrient levels leading to more luxuriant vegetation. The restriction of significant overbank sedimentation to facies I coals is noteworthy. It suggests that the forests grew adjacent to fluvial channels, and/or that its mires were more susceptible to clastic inundation than were sub-aquatic environments dominated by reed and herbaceous vegetation.

Structured biomass in facies I may partially reflect the contribution of subaerial root tissue. There is a strong association between this material and clearly identifiable wood varieties, indicating a sympathetic relationship with the forest-derived coals. Discrete zones rich in tissue interpreted to be largely of sub-aerial origin do occur, but are rare. A similar phenomenon has also been reported in Eocene peats that accumulated in tropical settings (Stach *et al.*, 1982).

#### 6.6.1.2 Development of sub-facies

Within the facies I setting there appear to have been several local sub-environments, each with a different combination of groundwater level, pH, redox potential and hence degree of biomechanical degradation. Depending on the precise nature of these conditions a variety of sub-facies developed from similar source material. Sub-facies Ia coals, in which structured biomass is abundant (as shown by large woody fragments and subaerial root tissue), are interpreted to reflect the lowest level of tissue breakdown and show features consistent with forest swamp environments (Taylor *et al.*, 1998). Occasional mineral enrichment in sub-facies Ia coal suggests a causal relationship between tissue preservation and overbank sedimentation (i.e. rapid burial associated with clastic input and a shorter period of exposure to near-surface aerobic conditions, and/or increased plant growth in a nutrient-rich environment).

The maceral assemblages of sub-facies Ib and Ic are similar to that of sub-facies Ia, particularly with respect to liptinite composition and the level of gelification. A common source material is indicated. However, the progressive changes from sub-facies Ia, through Ib to Ic are all consistent with increasing levels of biomechanical degradation (Figure 6.3). These include lower wood contents; diminished tissue preservation as shown by liptinite fragmentation (mean liptodetrinite content = 6, 7 and 33%, respectively); increasing inertinite abundance (mean contents = 1, 2 and 4%, respectively) and abundant bituminite in sub-facies Ic. The duration and severity of aerobic exposure as highlighted by Anderson and Mackay (1991) and Moore and Shearer (2003) is likely to be a key factor in this process and possibly corresponds with drier conditions (Holdgate *et al.*, 1995). Increased breakdown of the most susceptible components may also reflect the onset and maintenance of more pronounced ombrogenous conditions. A corresponding change in vegetation (to a less forested

environment and/or a less resistant angiosperm flora) would further assist tissue degradation (Kolcon and Sachenhofe, 1999; Bectel *et al.*, 2003). Furthermore nutrient-poor environments able to support only a stunted vegetation are widely postulated for ombrogenous settings (Moore, 1989; Diessel, 1992).

The origin of high-liptinite[1] 'pale' coals (i.e. sub-facies Ic from the present study) has been debated extensively (Teichmuller, 1989; Diessel, 1992; Taylor *et al.*, 1998; Dehmer, 2004). They are commonly attributed to intense aerobic bacterial activity (typically under low groundwater conditions) leading to selective degradation of woody tissue and hence enrichment of the residual liptinite (Stach *et al.*, 1982; Winkler, 1986; Anderson and Mackay, 1990; Ming *et al.*, 1994; Holdgate *et al.*, 1995; Taylor *et al.*, 1998). In addition, deposition of allochthonous liptinite into treeless subaquatic environments has also been invoked, especially for sporinite-rich coals (Teichmuller, 1982, 1989; Kershaw and Sluiter, 1982; Kershaw *et al.*, 1991). In the Lochiel and Bowmans Deposits, selective liptinite enrichment through extreme degradation of vascular plant tissue is considered the most likely mechanism. Abundant bituminite formation and elevated funginite (both of which are consistently more abundant in this coal variety than in any other), together with very low levels of tissue preservation, are all interpreted as a reflection of extreme bacterial and fungal degradation under aerobic conditions (Teichmuller, 1989; Crosdale, 1993; Dehmer, 2004; Taylor *et al.*, 1998). Fluctuating groundwater level, an ombrogenous setting, or a hiatus in deposition could provide such conditions, with the former highlighted by Moore and Shearer (2003) as promoting intense degradation.

A change in the nature of the source material is postulated for the rare sub-facies Ib coal that is characterised by extreme resinite enrichment. This variety is considered to reflect modification by resin bleeding from vascular tissue and is likely to constitute a localised feature of limited lateral extent.

### 6.6.2 Facies II

#### 6.6.2.1 Primary environment

Facies II is interpreted to be the product of topogenous subaquatic peat accumulation, coinciding with elevated water table conditions. Such a setting would account for the advanced gelification, microbanding of maceral constituents and high degree of tissue preservation that are typical of this facies (Diessel, 1992; Taylor *et al.*, 1998). The dominance and preservation of fine cutinite, which can typify plants from wet environments (Stach *et al.*, 1982; Diessel, 1992), and the lack of terrestrial liptinites including resinite, suberinite and

[1] High-liptinite in this thesis is used to mean significantly elevated liptinite in humic coals and does not imply torbanite, or cannel coals

thick cutinite, further support a non-forested environment. Within such a setting devoid of large woody flora, organic input could possibly be restricted to soft tissue herbaceous plants and marsh vegetation. Larger intact tissue remnants, where present, are typically well gelified and are possibly indicative of *in situ* root growth.

The low maceral diversity and high tissue preservation of facies II coals are suggestive of a highly autochthonous source for its organic matter, with the notable exception of its large fusinite phytoclasts. Significantly, the latter are largely restricted to this facies, although fire and fusinite may have been ubiquitous throughout the peat-forming period, especially in the drier, well-vegetated areas of the northern St. Vincent Basin. Furthermore, these fusinite phytoclasts are relatively well distributed vertically and laterally, indicating ongoing generation and widespread mobilisation. Conjunction of the optimum conditions necessary for the generation, distribution and preservation of fusinite appears to have occurred only in facies II and more specifically sub-facies IIb. However, the precise origin of the fusinite (i.e. relative extent of allochthonous and hypautochthonous inputs) is not fully resolved. Smaller fusinite particles could possibly be aeolian (Kershaw *et al.*, 1991), whereas larger fragments may have floated or been washed in from near the margins of the swamp , with increased runoff after wildfire events facilitating relatively even and widespread dispersal (Scott, 1989; Taylor *et al.*, 1998; Glasspool, 2003). Transportation and distribution are possibly the critical parameters unique to this facies and they would be optimised in a subaquatic environment. An alternative explanation is for the development of facies II environments to coincide with periods of widespread fusinite generation, although specific evidence for such timing was not detected.

Palaeobotanical information pertaining to facies II is mainly limited to cuticular evaluation, whereby Rowett (1992) detected a nearly monospecific floral assemblage which is very distinct from that of facies I. Such a profound change of vegetation is consistent with a major change in groundwater regime. Based on a tentative cuticular identification of the angiosperm *Oleaceace,* a relatively dry setting may be inferred for facies II (A.J. Rowett, pers. comm., 1994). This appears to contradict the findings of the present study. However, conflict between petrographic and palaeobotanical reconstructions of fossil vegetation is not unusual (Teichmuller, 1989; Holdgate *et al.*, 1995) and commonly reflects factors such as dispersal and reworking. While not yet fully resolved, a similar explanation may also apply in this situation, with input of the oleaceaean cuticle perhaps being from a drier hinterland.

### 6.6.2.2 Sub-facies development

Slight variations in source material consequent upon changes in relative water depth and proximity to the forest settings of facies I are possibly key factors in the development of sub-facies. In settings transitional between terrestrial and subaquatic conditions, several local environments are suggested to have resulted in several varieties of sub-facies IIa, while sub-facies IIb is interpreted to represent more distal settings of permanent standing water.

Sub-facies IIa shares some of the same elements as facies I and is envisaged to represent accumulation in areas of shallow permanent standing water, proximal to terrestrial forests. While the groundwater conditions appear sufficient to have precluded the growth of large trees, its weaker gelification (relative to sub-facies IIb) suggests that a slight water level differential existed between the facies II sub-types. Significantly, large phytoclasts of fusinite are less common in sub-facies IIa, consistent with a lower groundwater level and hence a lesser potential for their distribution. Subtle differences between the sub-facies IIa coals from Lochiel and Bowmans may reflect the differing nature of their facies I/II interfaces. The higher terrestrial liptinite content at Bowmans may reflect increased hypautochthonous mobilisation of terrestrial constituents. The sub-facies IIa-3 variety (with abundant cutinite and well-defined bedding) resembles the paper coals described by Stach *et al.* (1982), wherein floating and hypautochthonous or allochthonous constituents become concentrated in a subaquatic setting (Taylor *et al.*, 1998; Glasspool, 2003).

Subaquatic, treeless conditions in a distal setting removed from the forested hinterland are envisaged for sub-facies IIb. In this environment, input of the allochthonous terrestrial liptinite found in sub-facies IIa coals is essentially precluded. The low maceral diversity and high tissue preservation of sub-facies IIb suggests a mostly autochthonous peat, and is also consistent with the low floral diversity inferred from palaeobotanical investigation. More intensive gelification, better tissue preservation and a greater abundance of fusinite than in sub-facies IIa are all supportive of stable subaquatic conditions and, more specifically, of slightly deeper water, dominated by reeds and possibly some herbaceous plants.

### 6.6.3 Facies III

Facies III coals display some sapropelic characteristics, such as a uniformly fine particle size, microstratification and a homogenous texture (Diessel, 1992; Taylor, 1998). Other features such as alginite and highly gelified vitrinite are indicative of lacustrine conditions (Diessel, 1992), while the diverse liptinite assemblage and enhanced abundance of fine inertodetrinite suggest a significant allochthonous input. Thus, facies III appears to comprise a mixture of fine allochthonous (fluvial and/or aeolian) organic matter, together with some plankton and detritus of water plants, deposited in a local depression or lake. Within such a setting the

organics would be laid down as subaquatic muds under anoxic conditions (Stach *et al.*, 1982; Ward, 1984).

With regard to possible water depth there is no evidence of root growth, while the presence of alginite and high gelification provide limited guidance. However, the occurrence of facies III coals within an otherwise humic sequence, and the dominance of organic detritus over mineral matter, suggest a shallow, albeit open-water setting. Higher mineral contents are possibly indicative of deeper conditions.

### 6.6.4 Facies IV

Facies IV coals are interpreted to be alteration products of any of the primary coal types. Its two sub-facies differ substantially according to the mechanism of their alteration. Syn-depositional exposure leading to peat combustion and post-depositional weathering are inferred for sub-facies IVa and IVb, respectively.

#### 6.6.4.1 Sub-facies IVa

The abundance of macrinite, presence of oxidation rims and volatilisation of liptinites in the coal of sub-facies IVa suggests desiccation and partial combustion of peat horizons (Diessel and Smyth, 1995; Taylor *et al.*, 1998; Scott, 2002; Figure 6.12), although the intensity of this alteration varies considerably over short intervals. The fact that this coal is directly overlain by silts is also consistent with the development of topographic depressions and lacustrine conditions following combustion (Teichmuller, 1989). Modification of the peat in this way may have followed a hiatus, or a lowering of the water table, with subsequent exposure and is indicative of relatively dry conditions, (Rollins *et al.*, 1993).

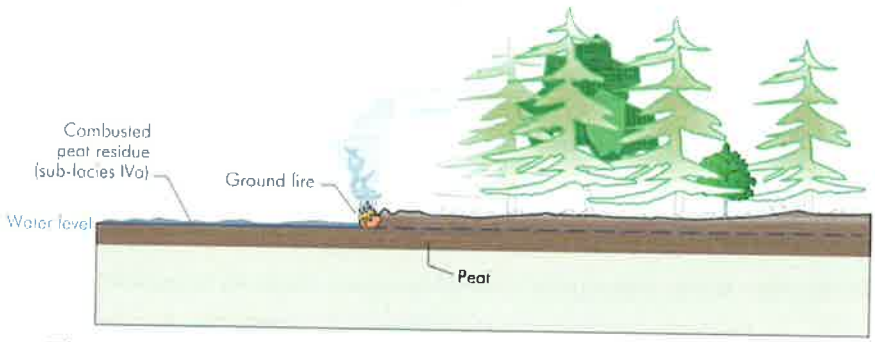



Figure 6.12 Ground fire leading to sub-facies IVa formation

The differing modes of sub-facies IVa occurrence most likely reflect the relative extent of the reworking of the parent peat following desiccation and/or combustion. The irregular bands consisting entirely of oxidised peat fragments are *in situ* debris horizons on which peat

accumulation subsequently resumed with minimal disturbance. They differ from the more stratigraphically regular horizons of dispersed inertinite-rich grains within unmodified vitrinitic groundmass, which are interpreted as redistributed remnants of partially combusted plant material, although the specific site of combustion and the manner of its distribution and incorporation into the primary peat remain unclear. Possible mechanisms include *in situ* formation with local reworking, or the introduction of allochthonous particles following their generation elsewhere. The size of the remnant particles, the lack of increased mineral content (from associated fluvial transport) and the limited lateral extent of the horizons support the former scenario. However, some inconsistencies remain. Its primary textural characteristics are those of a facies II coal, none of which was found within the subadjacent stratigraphic interval; the regularity of the horizons contrasts strongly with the major vertical fluctuations evident wherever thicker *in situ* debris occurs; and the coal immediately above and below the disseminated horizons is relatively uniform in texture and composition. Together these features are indicative of an allochthonous material introduced following formation from proximal facies II peats. This issue is not yet fully resolved, although on balance the latter scenario is favoured.

The significance of the widespread derivation of sub-facies IVa coals from subaquatic peats (i.e. facies II and III) is unclear. These well-gelified, wood-poor peats may be more susceptible to desiccation and combustion than the forest-derived facies. Alternatively, the correlation may be coincidental and related to their distribution within the upper portion of the coal sequence (see Section 7.4.4).

#### 6.6.4.2 Sub-facies IVb

Weathering during periods of hiatus and exposure is postulated to account for sub-facies IVb. This process affected mainly the physical properties of the peat, with no appreciable change in vitrinite reflectance due to oxidation, as noted in weathered coals by Stach *et al.* (1982). The usual development of sub-facies IVb at the uppermost level of a given seam, and especially in the youngest Lochiel seam (i.e. F Seam), together with the gradational nature of its contact with the underlying primary coal, are all consistent with its origin via physical weathering.

The most intense weathering appears to have occurred after the conclusion of peat formation and may correspond with the depositional hiatus in the Lochiel area proposed by Kremor (1992). Some evidence also exists for limited exposure and weathering late within the coal sequence, followed by a resumption of peat accumulation.

## 6.7 SUMMARY

The eight coal types identified in the Lochiel and Bowmans Deposits are classified into three primary facies groups and one altered facies group (Table 6.5; Figure 6.10). Each grouping is considered to reflect a particular local palaeoenvironment (Figure 6.11), while sub-facies represent varying levels of biomechanical degradation of a common source material, or subtle differences in organic input.

Table 6.5 Coal facies and their interpreted palaeoenvironments

| Facies | Palaeoenvironment |
|---|---|
| Facies I | Forest swamp. Large trees and high diversity of flora. Three sub-facies, derived from a common biomass, record increasing tissue degradation in line with increasing severity and duration of aerobic exposure. |
| Facies II | Subaquatic marsh. Small herbaceous and marsh vegetation, of possibly limited diversity. Two sub-facies record subtle changes in source material, possibly reflecting position relative to adjacent terrestrial forest environments and groundwater table. |
| Facies III | Open water lacustrine. Detrital plant and planktonic inputs. |
| Facies IV | Altered coals. Two unrelated sub-facies reflect desiccation/combustion and weathering of primary peats. |

Facies I coals are characterised by their high liptinite contents (notably resinite and suberinite) and poorly gelified vitrinite, while some varieties also contain abundant (commonly large) wood fragments. The latter component is mainly restricted to this facies. A high-rainfall, mixed gymnosperm-angiosperm forest setting is interpreted for facies I, with groundwater conditions possibly fluctuating between shallow topogenous and ombrogenous. Three sub-facies were defined. Together they record a progressive increase in tissue breakdown and the resulting concentration of resistant lipid-rich constituents, from sub-facies Ia to sub-facies Ic. These sub-facies are interpreted to reflect increasing exposure of the plant detritus to oxic conditions (i.e. severity and/or duration) in turn attributable to fluctuating groundwater levels, ombrogenous conditions, non-deposition and/or periods of reduced precipitation.

Facies II is represented by dark, humic coals containing a mixed assemblage of terrestrial and aquatic liptinites, abundant fragmented groundmass tissue and moderately to strongly gelified vitrinite. The overall level of tissue preservation in these coals is moderate to high. Although a minor component, inertinite (especially fusinite) is somewhat more abundant than in the other facies, suggesting widespread fires and a conjunction of optimum conditions for its introduction and preservation. Peat accumulation under subaquatic conditions, dominated by reeds and small herbaceous plants is inferred. Two sub-facies and several varieties have been defined and are thought to reflect subtle changes in the mire environment and possibly also in its proximity to the forested hinterland. A setting transitional between forest and largely treeless/reed dominated mire, and expansive areas of possibly slightly deeper reed mire are inferred for sub-facies IIa and sub-facies IIb, respectively.

Facies III coals are dark and highly gelified, contain both aquatic and very fine terrigenous organic detritus, and show some sapropelic characteristics. While detrovitrinite is their dominant maceral, mineral matter and inertinite can be significant components, and microstratification is common. They represent the accumulation of a fine organic mud under open-water lacustrine conditions.

Two varieties of altered coal comprise facies IV. One is noticeably enriched in inertinite, while the other has a friable and fractured appearance. These coals are respectively interpreted to be relics of short-lived desiccation and combustion during peat formation (sub-facies IVa), and of exposure and weathering in the latter stage of peat accumulation in the northern St. Vincent Basin (sub-facies IVb).

Within each facies subtle differences are evident between the Lochiel and Bowmans Deposits. The most significant include better liptinite preservation across the coal suite, increased abundance of resinite and suberinite, and generally lower contents of inertinite (especially within facies II) at Bowmans. Enhanced tissue preservation and reduced coal diversity at Bowmans may indicate that consistently wetter conditions prevailed there, in marked contrast to the fluctuating water table and oxic/anoxic interface at Lochiel.

## PLATE 6.1
## SUB-FACIES Ia - GROUNDMASS

a Woody coal: Wood rich coal showing several dark fragments of varying size, within a medium brown, earthy, low tissue groundmass.
*Hand specimen, Lochiel Deposit, S12 - 5.40 m, (113), sub-facies Ia.*

b Well preserved liptinite: Large resinite with a number of smaller resinite bodies, sporinite, fragmented suberinite and some liptodetrinite. Overall liptinite preservation is high compared to other facies I sub-varieties.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 73, sub-facies Ia, negative no. 41/5t.*

c Detrovitrinite and large liptinites: Poorly gelified attrinite groundmass, with large (dark brown) liptinite phytoclasts.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 73, sub-facies Ia, negative no. 41/4.*

d Well preserved liptinite: Large cutinite, with smaller resinite, sporinite, fragmented suberinite and liptodetrinite. This represents a typical terrestrial assemblage, but shows higher liptinite preservation than other facies I sub-varieties.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.1c, Lochiel Deposit, V714 - 73, sub-facies Ia, negative no. 41/3.*

e Detrovitrinite and large liptinites: Poor (to moderately) gelified attrinite groundmass, with larger (dark brown) liptinite phytoclasts.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 71, sub-facies Ia, negative no. 40/20.*

f Well preserved liptinite: Several large resinite and suberinite phytoclasts, with minor liptodetrinite. This represents a typical terrestrial assemblage and reflects higher liptinite preservation than other facies I sub-varieties.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.1e, Lochiel Deposit, V714 - 71, sub-facies Ia, negative no. 40/21.*

g Detrovitrinite: Poorly gelified attrinite groundmass mostly devoid of telovitrinite and gelovitrinite.
*Photomicrograph, white reflected light, Lochiel Deposit, S12 - 102, sub-facies Ia, negative no. 25/19.*

h Groundmass liptinite: Resinite phytoclasts with sporinite and minor liptodetrinite forming the groundmass liptinite where larger liptinite phytoclasts, (i.e. cutinite, suberinite, resinite) are absent.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.1g, Lochiel Deposit, S12 - 102, sub-facies Ia, negative no. 25/21.*

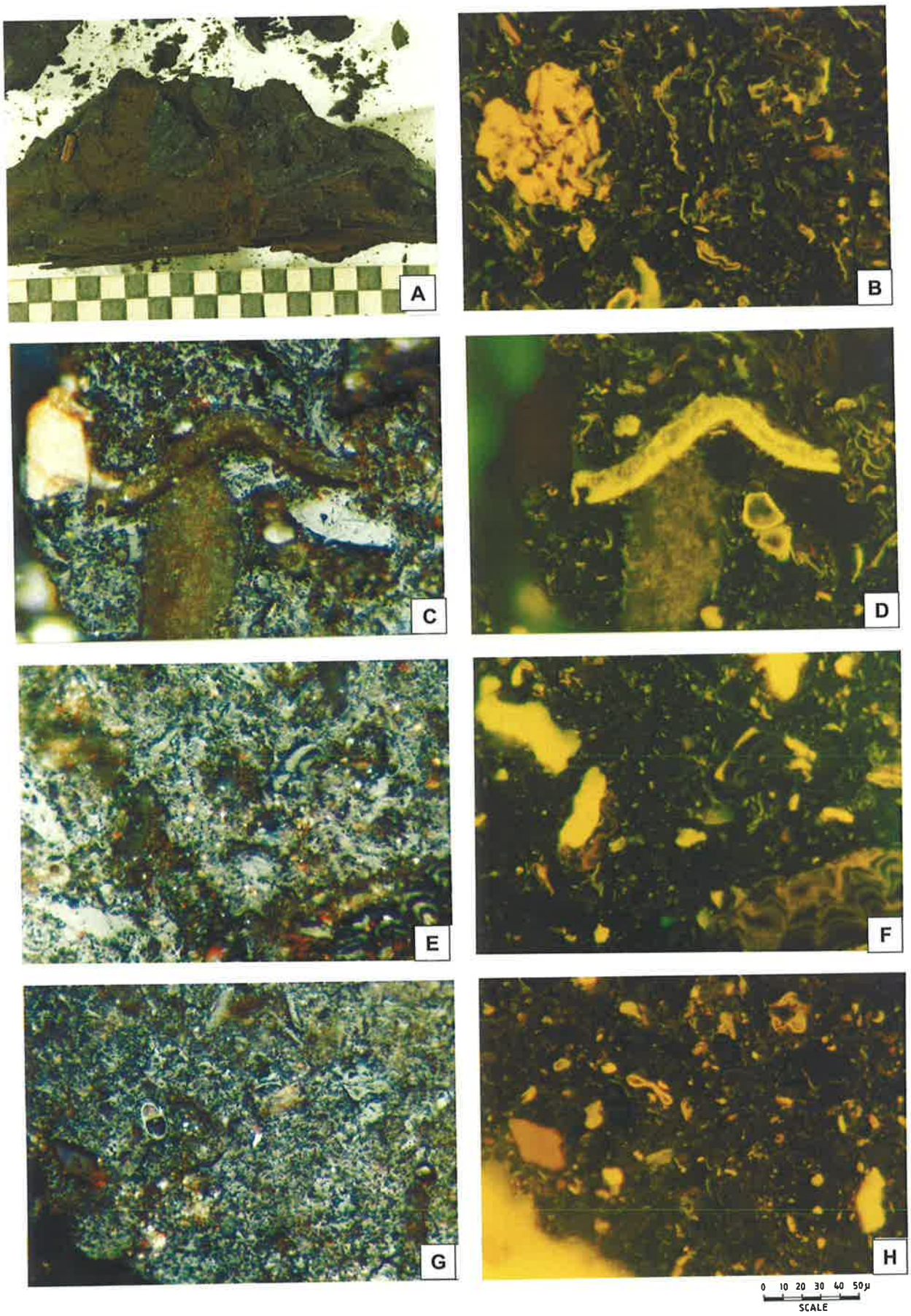



**PLATE 6.1**

## PLATE 6.2
## SUB-FACIES Ia - TISSUE

a Woody coal: Wood rich coal showing a large, very fibrous fragment within a earthy, low tissue groundmass.
*Hand specimen, Lochiel Deposit, S12 - 5.40 m, (113), sub-facies Ia.*

b Massive texto-ulminite: Large phytoclast consisting entirely of texto-ulminite, showing mostly open lumens.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 72, sub-facies Ia, negative no. 35/18.*

c Massive texto-ulminite: Large phytoclast consisting entirely of texto-ulminite with significant corpogelinite and porigelinite infilling. Cell walls are distinct.
*Photomicrograph, white reflected light, Lochiel Deposit, S12 - 101, sub-facies Ia, negative no. 25/6.*

d Massive eu-ulminite: Large phytoclast consisting entirely of eu-ulminite in which cell lumens are mostly filled. Cell walls are visible, but not always distinct. This variety is common within W2 wood particles.
*Photomicrograph, white reflected light, Lochiel Deposit, L402, sub-facies Ia, negative no. 37/12.*

e Massive texto-ulminite: Large phytoclast consisting entirely of texto-ulminite. Cell lumens are partially open and cell walls distinct.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 – 40, sub-facies Ia, negative no. 23/29.*

f Massive textinite: Large phytoclast consisting entirely of textinite. Cell lumens are open and show only very minor gelification.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 85.5 m, sub-facies Ia, negative no. 20/14.*

g Massive texto-ulminite: Large phytoclast consisting entirely of texto-ulminite. Cell infilling is almost complete.
*Photomicrograph, white reflected light, Bowmans Deposit, B5 - 85.5 m, sub-facies Ia, negative no. 20/13.*

h Massive suberinite: Large phytoclast consisting entirely of suberinite. Phytoclasts showing these characteristics are closely associated with W2 wood particles and possibly represent periderm fragments.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V672 - 37.70 m, L504, sub-facies Ia, negative no. 37/7.*

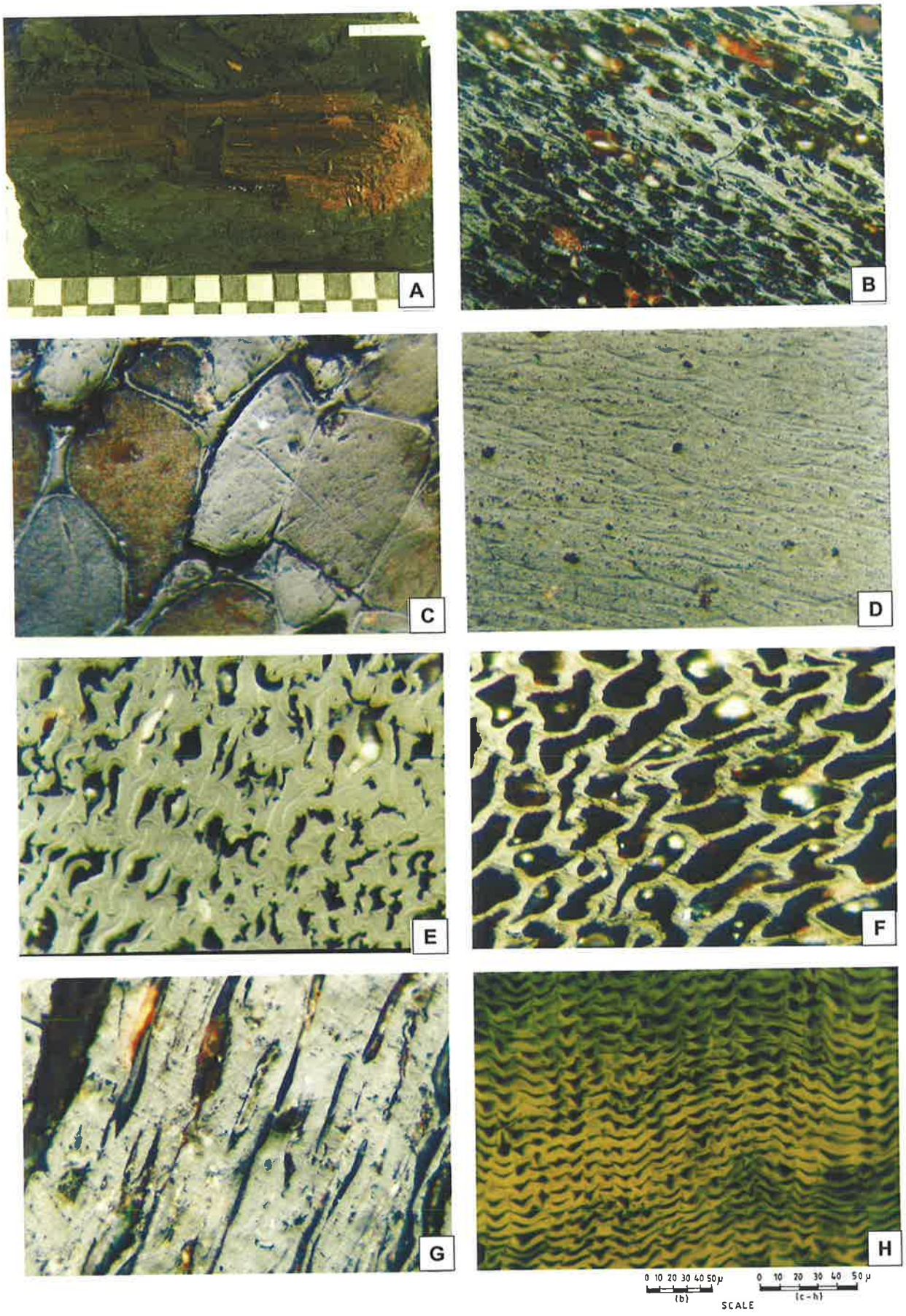



**PLATE 6.2**

## PLATE 6.3
## SUB-FACIES Ib

a Earthy coal: Medium brown, showing low wood and groundmass tissue contents.
*Hand specimen, Lochiel Deposit, S12 - 4.65 m (111), sub-facies Ib.*

b Poorly gelified vitrinite: Poorly gelified attrinite with a small, poorly preserved texto-ulminite phytoclast.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 36, sub-facies Ib, negative no. 23/11.*

c Poorly gelified vitrinite: Poorly gelified attrinite with a small poorly preserved texto-ulminite phytoclast and funginite.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 60, sub-facies Ib, negative no. 41/5.*

d Assorted liptinites: Typical terrestrial liptinite assemblage in high abundance, (i.e. suberinite, resinite, liptodetrinite and sporinite).
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.3c, Lochiel Deposit, V714 - 60, sub-facies Ib, negative no. 41/6.*

e Poorly gelified detrovitrinite: Poorly gelified attrinite including a funginite phytoclast.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 33, sub-facies Ib, negative no. 22/35.*

f Assorted liptinites: Abundant liptinite, rich in liptodetrinite and showing a typical terrestrial assemblage, (i.e. fragmented suberinite, resinite, liptodetrinite and sporinite).
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.3e, Lochiel Deposit, V704 -33, sub-facies Ib, negative no. 22/36.*

g Poorly gelified vitrinite: Poorly gelified attrinite groundmass and corpogelinite.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 60, sub-facies Ib, negative no. 41/10.*

h Assorted liptinites: Moderate to high liptinite abundance and a terrestrial assemblage, (i.e. fragmented suberinite, resinite, liptodetrinite and sporinite).
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.3g, Lochiel Deposit, V714-60, sub-facies Ib, negative no. 41/11.*

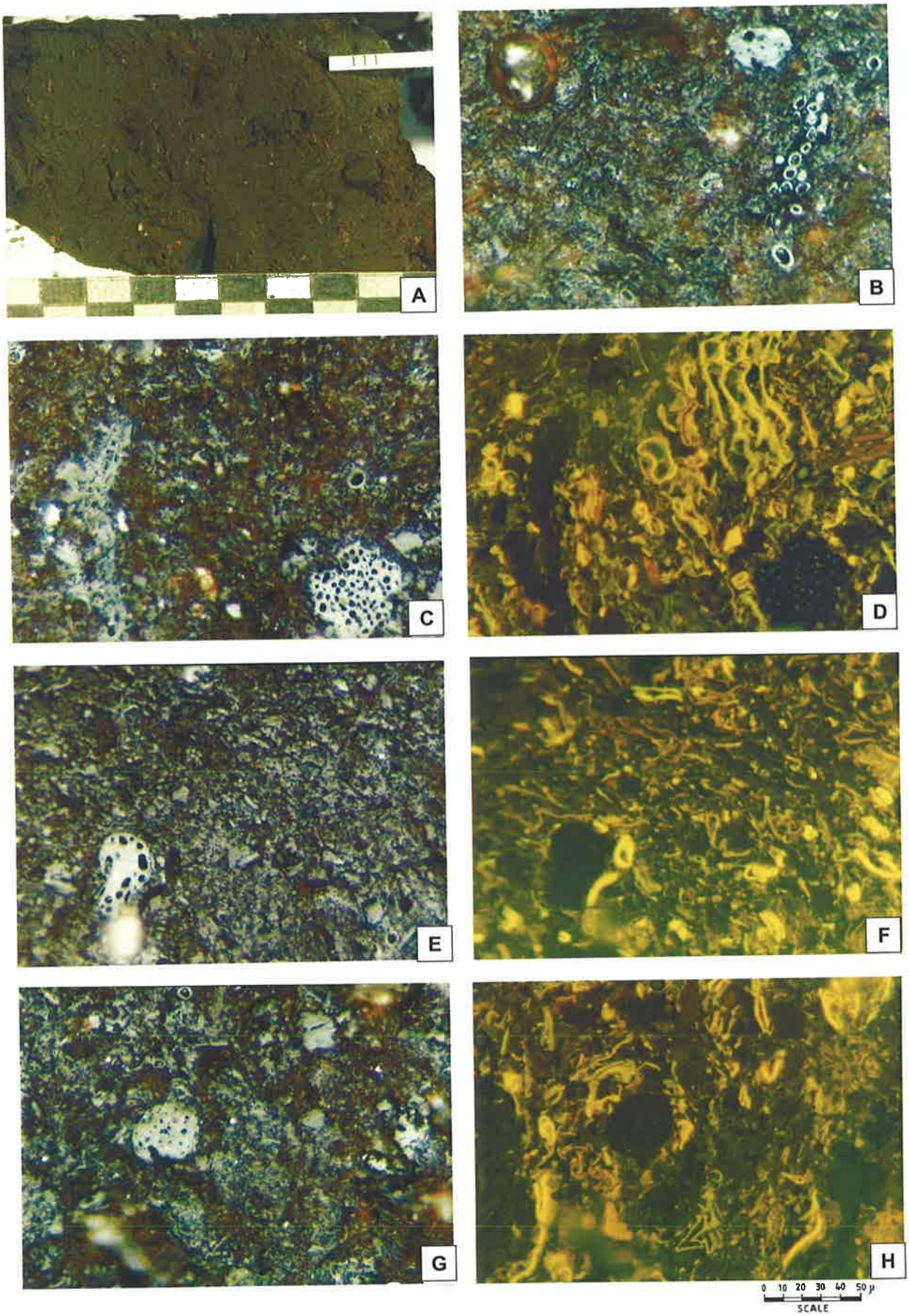



**PLATE 6.3**

## PLATE 6.4
## SUB-FACIES Ic

a Pale coal: Light with low wood and groundmass tissue contents.
*Hand specimen, Lochiel Deposit, V707 - 56.90 m, (L385), sub-facies Ic.*

b Abundant liptinite: Several large liptinites including resinite, cutinite and sporinite within a liptinite rich groundmass of liptodetrinite and bituminite.
*Photomicrograph, fluorescence mode, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 26/10.*

c Low vitrinite/elevated inertinite: Low vitrinite abundance (fine detrovitrinite and an absence of telovitrinite), with elevated inertinite (principally inertodetrinite).
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 27/26.*

d Abundant liptinite: Predominantly small liptodetrinite fragments within a bituminitic groundmass.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.4c, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 27/25.*

e Low vitrinite/elevated inertinite: Very low vitrinite abundance (mainly as very fine detrovitrinite), with an absence of telovitrinite. Inertinite (i.e. inertodetrinite and larger corpogelinite sourced fragments) is elevated.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 27/2.*

f Abundant liptinite: Some intact phytoclasts (i.e. sporinite and resinite), within a groundmass of liptodetrinite and bituminite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.4e, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 27/3.*

g Low vitrinite/elevated inertinite: Very low vitrinite abundance (i.e. fine detrovitrinite and absence of telovitrinite), with inertodetrinite.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 27/8.*

h Abundant liptinite: Intact phytoclasts (i.e. large cutinite, sporinite and resinite), within a groundmass of liptodetrinite and bituminite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.4g, Lochiel Deposit, V714 - 53, sub-facies Ic, negative no. 27/10.*

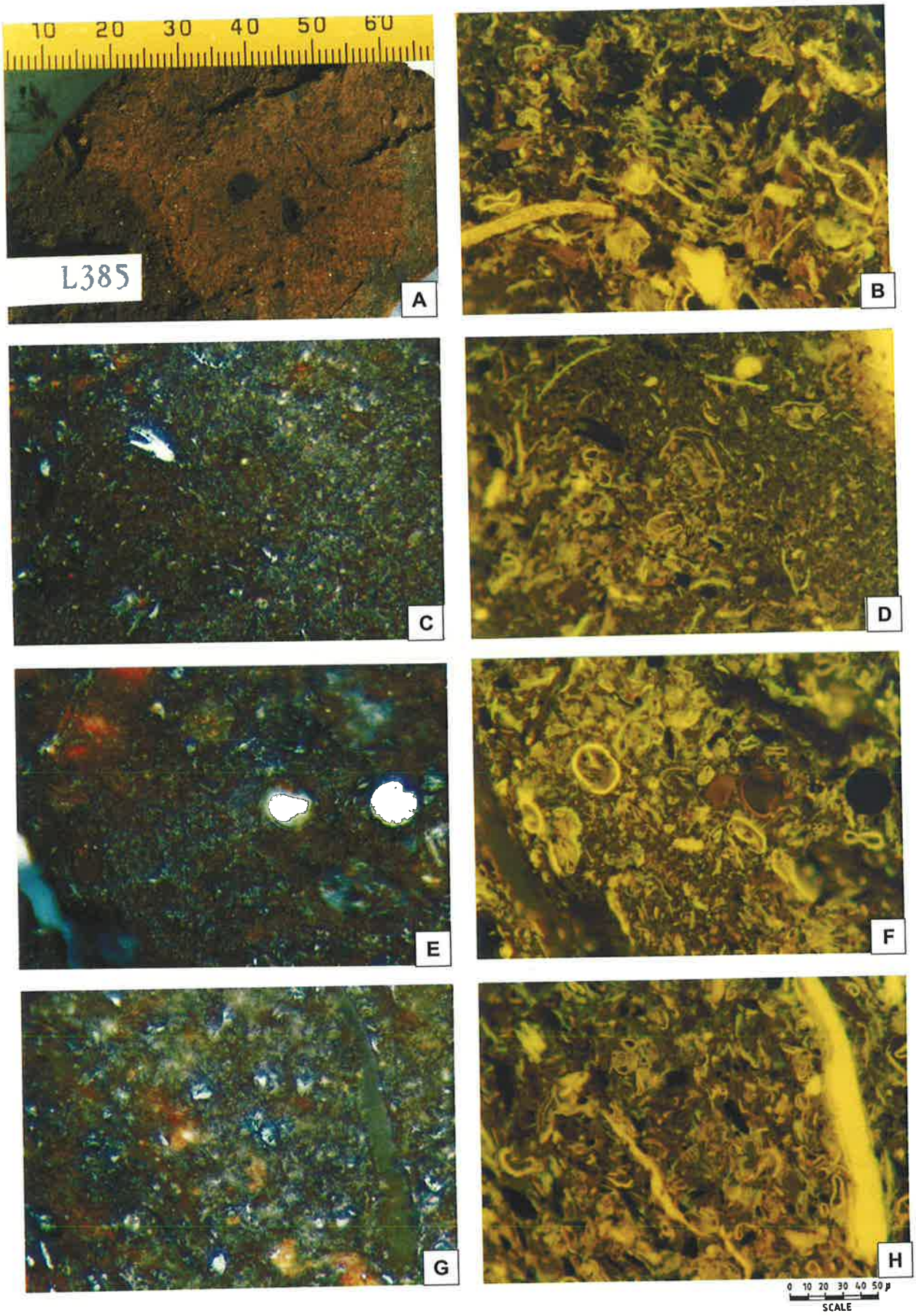



**PLATE 6.4**

## PLATE 6.5
## SUB-FACIES IIa

a Fibrous coal: Moderate to high groundmass tissue, dark coloured. Wood is absent.
*Hand specimen, Lochiel Deposit, V703 - 64.40 m, (L383), sub-facies IIa.*

b Well gelified vitrinite: Well gelified densinite groundmass with small phytoclasts of texto-ulminite.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 38, sub-facies IIa, negative no. 23/37.*

c Well gelified detrovitrinite: Well gelified densinite groundmass devoid of telovitrinite.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 63, sub-facies IIa, negative no. 40/9.*

d Moderate liptinite abundance and preservation: Fine liptodetrinite with some resinite and sporinite (i.e. a predominantly terrestrial assemblage). Liptinite abundance and size is reduced with respect to facies I coals.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.5c, Lochiel Deposit, V714 - 63, sub-facies IIa, negative no. 40/10.*

e Well gelified vitrinite: Well gelified densinite groundmass, containing an elongate texto-ulminite phytoclast. The latter is typical of sub-facies IIa.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 63, sub-facies IIa, negative no. 40/7.*

f Moderate liptinite abundance and preservation: Suberinite, resinite, sporinite and fine liptodetrinite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.5e, Lochiel Deposit, V714 - 63, sub-facies IIa, negative no. 40/8.*

g Well gelified vitrinite: Well gelified densinite groundmass, containing elongate texto-ulminite phytoclasts.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 63, sub-facies IIa, negative no. 40/5.*

h Low liptinite abundance and preservation: Low liptinite abundance, mostly fine liptodetrinite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.5g, Lochiel Deposit, V714 - 63, sub-facies IIa, negative no. 40/6.*

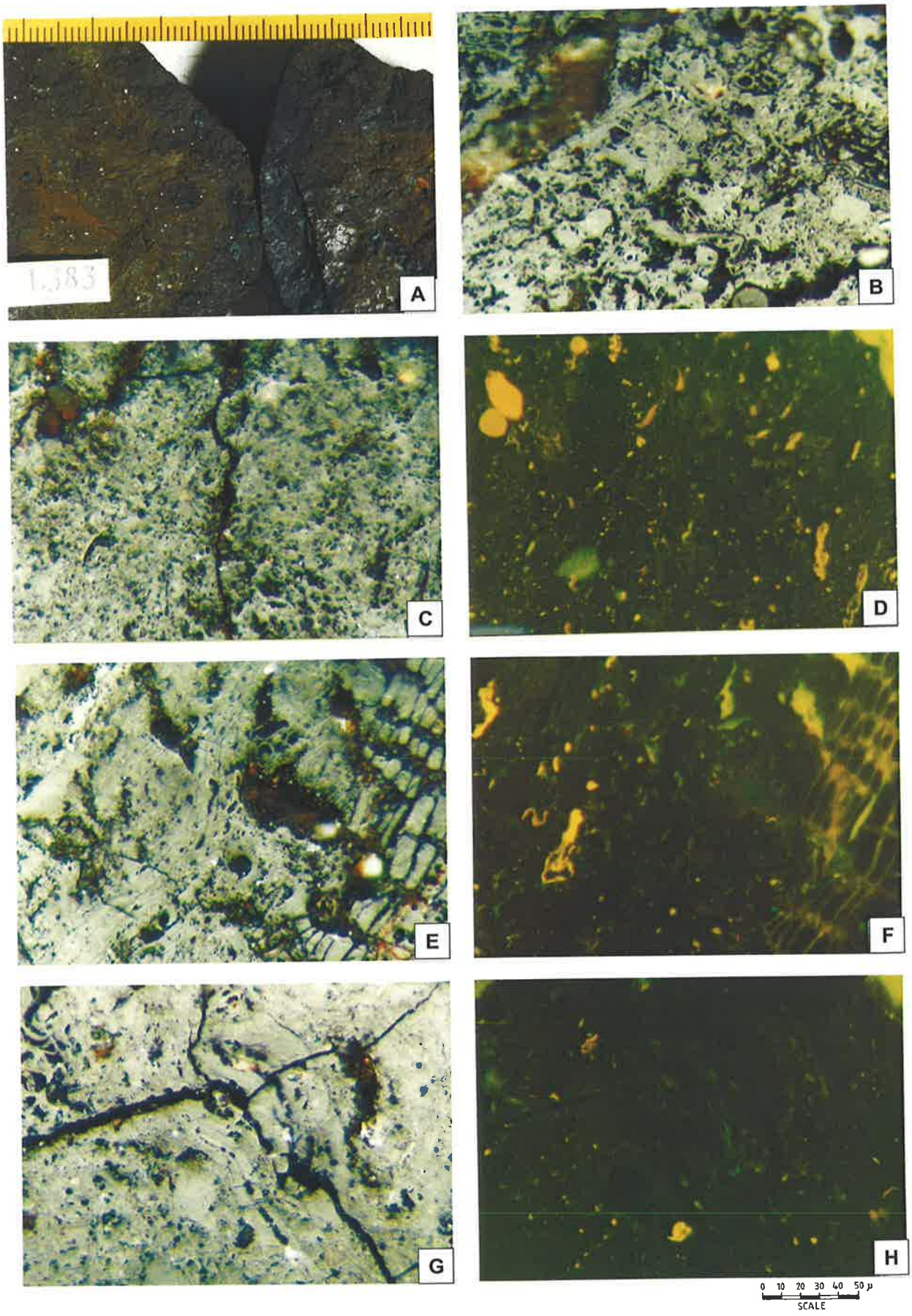



**PLATE 6.5**

## PLATE 6.6
## SUB-FACIES IIb

a Very fibrous coal: Abundant platy groundmass tissue consisting mainly of brittle, charcoal plates. Wood is absent and the coal dark.
*Hand specimen, Lochiel Deposit, V662 - 29.80 m, (P6/L391), sub-facies IIb.*

b Well gelified vitrinite with inertinite: Well gelified, mainly densinite groundmass, with variable sized phytoclasts of fusinite and inertodetrinite. Fusinite and elevated inertodetrinite are typical of sub-facies IIb.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 31, sub-facies IIb, negative no. 39/24.*

c Well gelified vitrinite with inertinite: Well gelified vitrinite groundmass of densinite and elongate eu-ulminite, with widespread inertodetrinite.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 31, sub-facies IIb, negative no. 39/21.*

d Low liptinite abundance: Low liptinite abundance, limited to mainly fine liptodetrinite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.6c, Lochiel Deposit, V704 - 31, sub-facies IIb, negative no. 39/22.*

e Elongate telovitrinite: Medium to large, elongate texto-ulminite phytoclasts within a densinite groundmass.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 28, sub-facies IIb, negative no. 22/3.*

f Well preserved fine cuticle: Liptinite assemblage limited to mainly thin, well preserved cuticle, which is commonly attached to texto-ulminite phytoclasts. This cutinite type is diagnostic of sub-facies IIb.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.6e, Lochiel Deposit, V704 - 28, sub-facies IIb, negative no. 22/4.*

g Elongate telovitrinite: Elongate texto-ulminite phytoclast within a moderately well gelified densinite groundmass. Texto-ulminite phytoclasts of this size and morphology are common in facies II coals.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 49, sub-facies IIb, negative no. 28/21.*

h Low liptinite abundance: Low liptinite abundance, mainly as fine liptodetrinite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.6g, Lochiel Deposit, V714 - 49, sub-facies IIb, negative no. 28/22.*

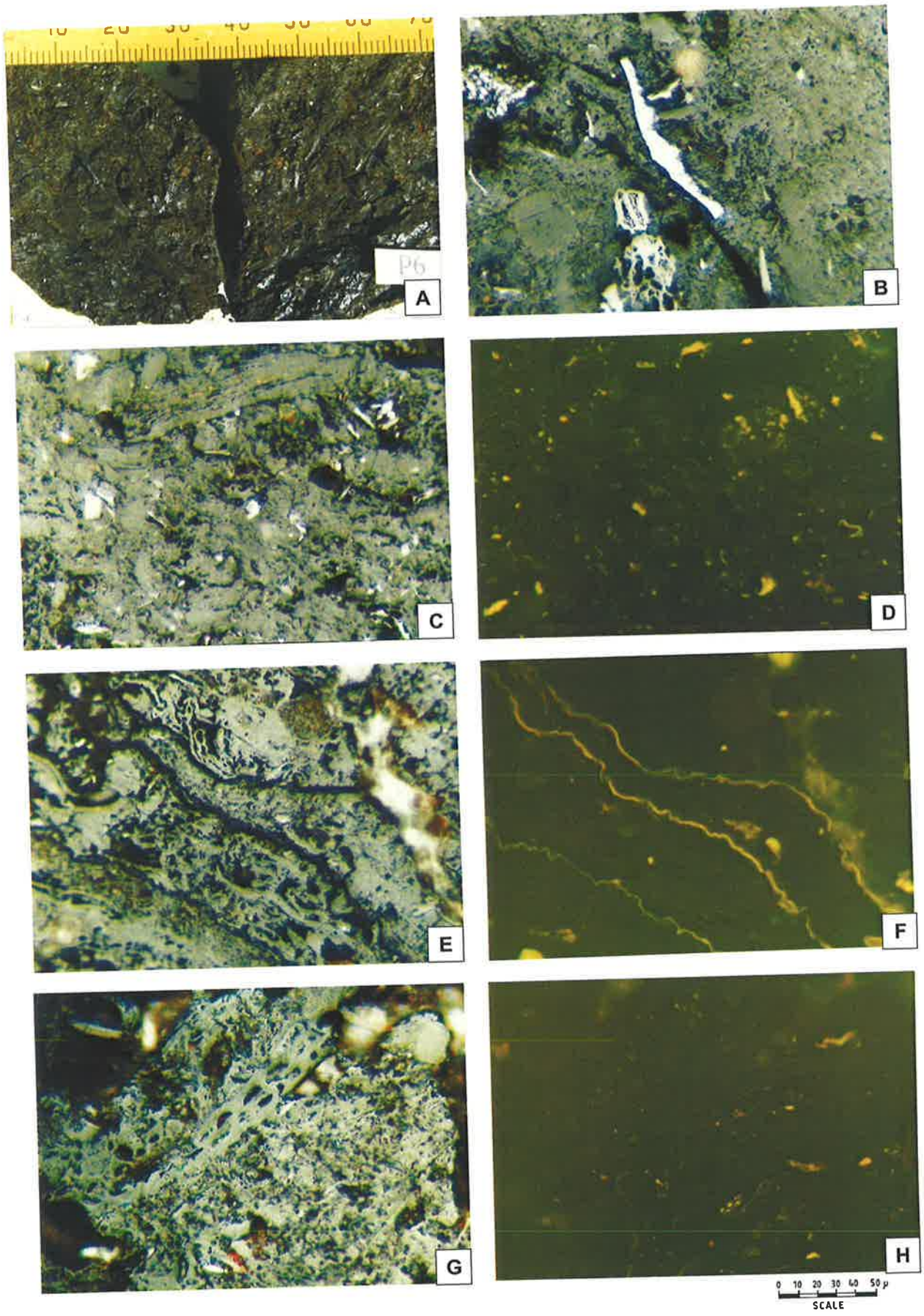



**PLATE 6.6**

## PLATE 6.7
## FACIES III - LOW MINERAL

a Very earthy coal: Dark, soft, highly gelified coal with only minor groundmass tissue.
*Hand specimen, Lochiel Deposit, V674 - 32.75m, (L535), facies III.*

b Well gelified detrovitrinite: Well gelified, mainly densinite groundmass, with minor telovitrinite. High gelification and low telovitrinite are typical of facies III.
*Photomicrograph, white reflected light, Lochiel Deposit, V704 - 43, facies III, negative no. 8/14.*

c Well gelified detrovitrinite: Very well gelified, mainly desmocollinite groundmass. Telovitrinite and inertinite macerals are absent.
*Photomicrograph, white reflected light, Lochiel Deposit, V674 - 32.75 m, (L535), facies III, negative no. 38/20.*

d Fine cutinite: Low to moderate liptinite abundance, mainly fine cuticle, with minor sporinite and liptodetrinite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.7c, Lochiel Deposit, V674 - 32.75 m, (L535), facies III, negative no. 38/22.*

e Well gelified detrovitrinite: Very well gelified, desmocollinite groundmass. Telovitrinite and inertinite macerals are absent.
*Photomicrograph, white reflected light, Lochiel Deposit, V673 - 27.9 m, facies III, negative no. 26/1.*

f Sporinite: Low liptinite abundance, mainly sporinite. The larger spore shows increased ornamentation, relative to more common forms.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.7e, Lochiel Deposit, V673 - 27.9 m, facies III, negative no. 26/2.*

g Well gelified detrovitrinite: Well gelified, mainly densinite groundmass. Minor telovitrinite phytoclasts.
*Photomicrograph, white reflected light, Lochiel Deposit, V674 - 32.75 m, (L535), facies III, negative no. 26/1.*

h Fluorinite and sporinite Fluorinite is uncommon, but diagnostic of this facies. Other liptinites in the field include sporinite and liptodetrinite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.7g, Lochiel Deposit, V674 - 32.75 m, (L535), facies III, negative no. 26/2.*

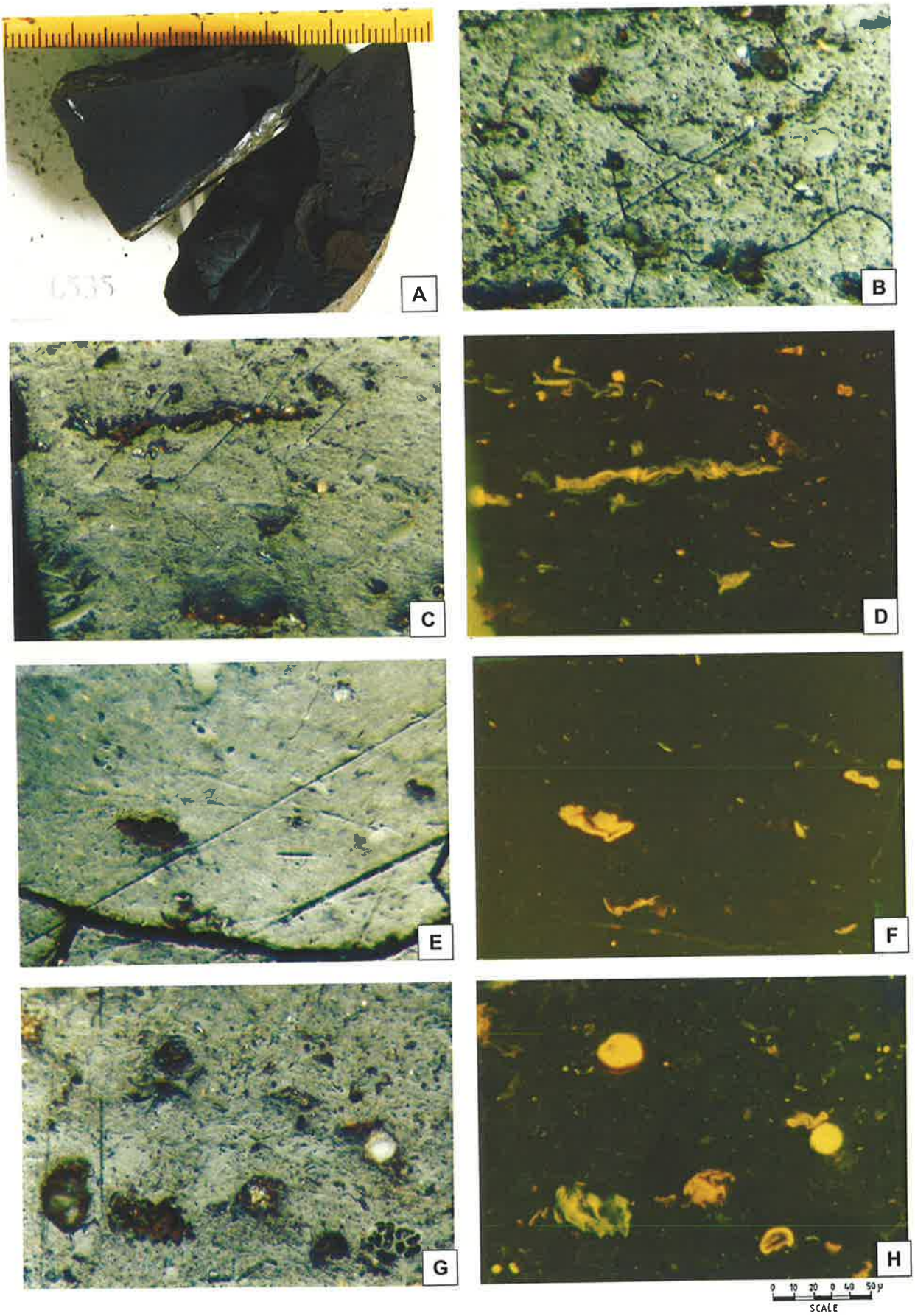



**PLATE 6.7**

## PLATE 6.8
## FACIES III - HIGH MINERAL

a Very earthy coal: Dark, soft, highly gelified coal with minor groundmass tissue. Some light, possibly mineral inclusions up to 0.5 mm.
*Hand specimen, Lochiel Deposit, V701 - 51.40m, (L377), facies III.*

b Very earthy coal: Dark, soft, highly gelified coal with very minor groundmass tissue.
*Hand specimen, Lochiel Deposit, Trial Pit, (L410), facies III.*

c Well gelified detrovitrinite with inertinite: Very well gelified, mainly desmocollinite groundmass, with inertodetrinite and fine mineral matter.
*Photomicrograph, white reflected light, Lochiel Deposit, V706 - 55.65 m, (L543), facies III, negative no. 38/23.*

d Alginite and sporinite: Distinctive aquatic assemblage of alginite and sporinite. High liptinite preservation.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.8c, Lochiel Deposit, V706 - 55.65 m, (L543), facies III, negative no. 38/24.*

e Well gelified detrovitrinite with inertinite: Very well gelified, mainly desmocollinite groundmass, with small fusinite phytoclasts and inertodetrinite.
*Photomicrograph, white reflected light, Lochiel Deposit, V706 - 55.65 m, (L543), facies III, negative no. 39/4.*

f Alginite and sporinite: Distinctive aquatic assemblage of sporinite with alginite. High liptinite preservation with essentially no liptodetrinite.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.8., Lochiel Deposit, V706 - 55.65 m, (L543), facies III,* negative no. *39/5.*

g Well gelified detrovitrinite with inertinite: Very well gelified, mainly desmocollinite groundmass, with small fusinite phytoclasts and inertodetrinite.
*Photomicrograph, white reflected light, Lochiel Deposit, V706 - 55.65 m, (L543), facies III, negative no. 39/1.*

h Alginite and sporinite: Distinctive aquatic assemblage of alginite and sporinite, showing high liptinite preservation.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.8g, Lochiel Deposit, V706 - 55.65 m, (L543), facies III, negative no. 39/2.*

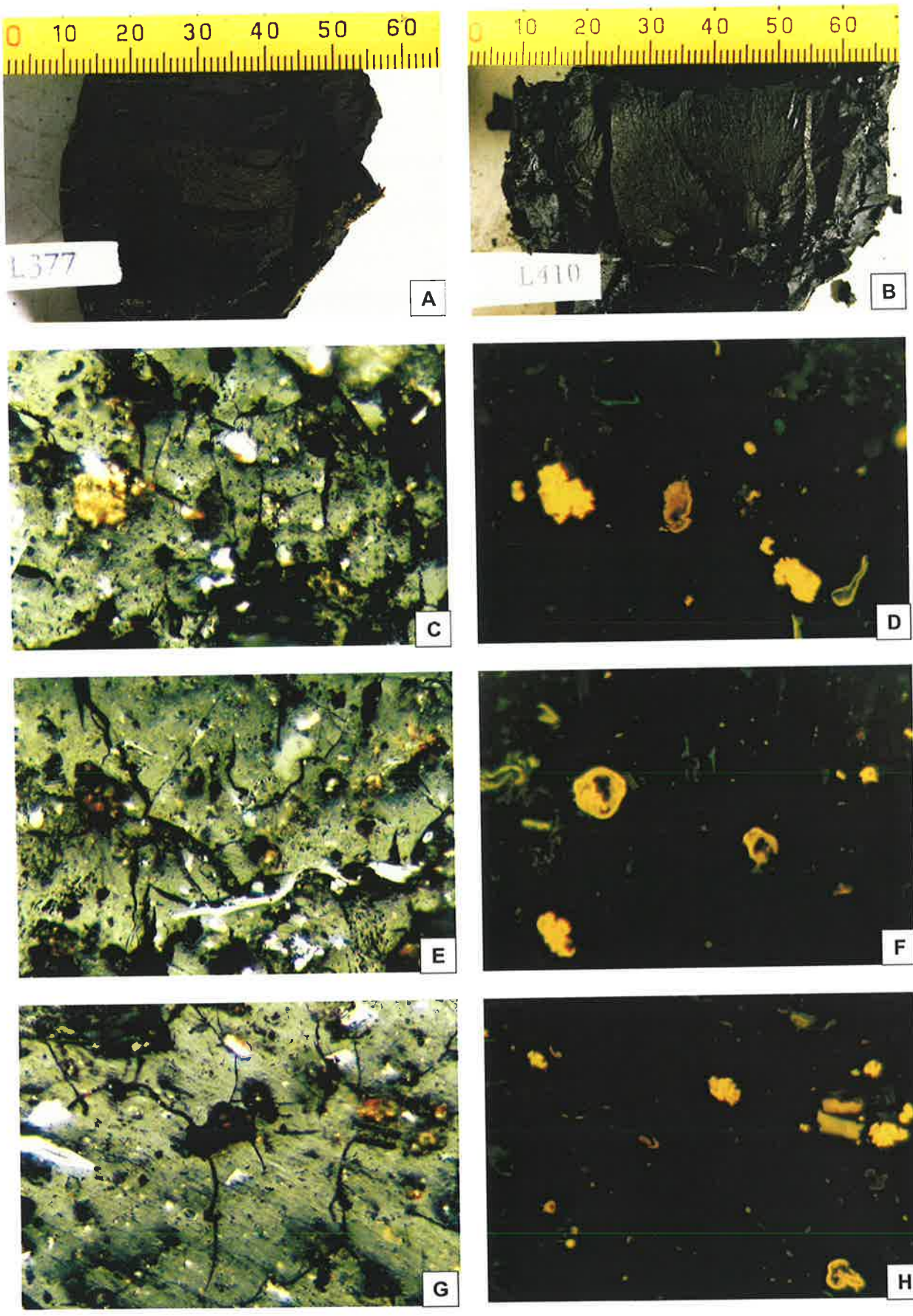



**PLATE 6.8**

## PLATE 6.9
## SUB-FACIES IVa

a Fractured coal: Highly fragmented, slightly vesicular association of dark, hard coal particles.
*Hand specimen, Lochiel Deposit, V706 - 55.85 m, (L544), sub-facies IVa.*

b Vitrinite and inertinite dominated grains: The inertinite dominated grain (i.e. sub-facies IVa) is shown on the right, in which the original 'detrital' texture is well preserved. (In facies I to III coals, inertinite constituents were introduced during peat accumulation).
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 58, sub-facies IVa, negative no. 35/16.*

c Vitrinite and inertinite dominated grains: The inertinite dominated grain (i.e. sub-facies IVa) is shown on the left.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 58, sub-facies IVa, negative no. 38/3.*

d Variable liptinite: Liptinite is absent from the inertinite dominated grain on the right, suggesting destruction concurrent with vitrinite oxidation.
*Photomicrograph, fluorescence mode showing identical, but rotated field of view as Plate 6.9c, Lochiel Deposit, V714 - 58, sub-facies IVa, negative no. 38/4.*

e Inertinite grain: All original constituents have been modified to inertinite, although the groundmass texture showing cellular and detrital fragments is well preserved.
*Photomicrograph, white reflected light, Lochiel Deposit, V706 - 55.85 m, (L544), sub-facies IVa negative no. 38/8.*

f Liptinite destruction: Liptinite is not present, however voids reflecting liptinite morphologies can be identified in plain reflected light, (i.e. plate 6.9-e).
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.9e, Lochiel Deposit, V706 - 55.85 m, (L544), sub-facies IVa, negative no. 38/10.*

g Inertinite dominated grain: Partial oxidation has occurred and reflectance is slightly elevated, although not so severe as in previous plates.
*Photomicrograph, white reflected light, Lochiel Deposit, V714 - 58, sub-facies IVa, negative no. 38/5.*

h Dull fluorescing liptinites: Liptinite macerals are detectable, but with a significantly reduce fluorescence, compared to primary (unaltered) coals.
*Photomicrograph, fluorescence mode showing identical field of view as Plate 6.9g, Lochiel Deposit, V714 - 58, sub-facies IVa, negative no. 38/6.*

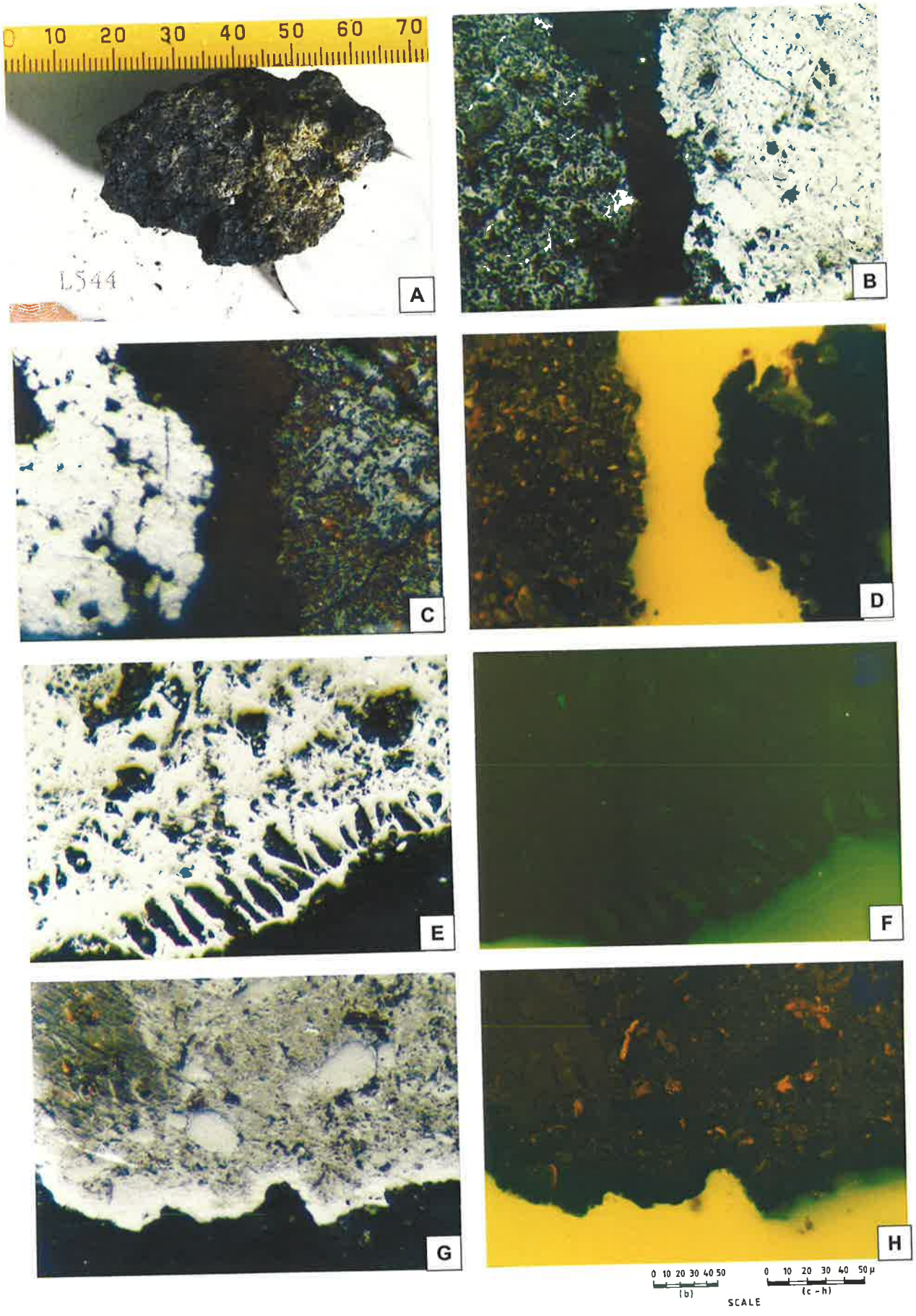

10 20 30 40 50 60 70
L544
A
B
C
D
E
F
G
H
0 10 20 30 40 50
(b)
0 10 20 30 40 50 μ
(c - h)
SCALE

**PLATE 6.9**

# 7 SPATIAL DISPOSITION OF THE COAL FACIES AND IMPLICATIONS FOR TEMPORAL EVOLUTION OF LOCAL PALAEOENVIRONMENTS

The spatial (i.e. three-dimensional) disposition of coal throughout the Lochiel and Bowmans Deposits is the subject of this chapter. For each deposit the ply stratigraphy of its constituent seams is first defined and the attributes of each horizon summarised. Attention is then directed to the coal facies that make up each seam and, in particular, the manner in which they occur and are distributed throughout the Eocene-Oligocene coal-bearing succession of the northern St. Vincent Basin. These stratigraphic findings are finally used to assess the temporal evolution of local palaeoenvironments and to develop a model of peat accumulation that accounts for the differences between the two deposits.

## 7.1 PLY DEFINITION AND EVALUATION

The presence of multiple coal types within seams results in banding and plies. A total of 13 and 16 coal plies were defined in the Lochiel and Bowmans Deposits, respectively. Plies were informally named using the established seam nomenclature and their relative position within the seam (e.g. G-3 for third ply from base in Seam G) and are independent of the coal facies classification. However, in all cases ply boundaries correspond with either facies or sub-facies boundaries. Furthermore, while coal type is not necessarily static for the full ply interval, the components of each ply are normally limited to coals from a single facies group. Where multiple sub-facies occur within a ply, they usually belong to facies I.

The confidence associated with ply definition differs between deposits, with a higher level at Lochiel reflecting relatively close spaced investigation sites (averaging less than 1 km), regular seam geometry, clear coal differentiation and the occurrence of distinctive and diverse facies types. This results in clear and readily identifiable banding. In contrast, the understanding of coal ply stratigraphy and ply correlation at Bowmans is limited, with reliable correlation restricted to a few distinctive horizons. This lower confidence at Bowmans is a function of high seam variability; low facies diversity, in combination with gradational change in coal characteristics; and fewer investigation sites (i.e. 5 at Bowmans compared to 38 at Lochiel; see 3.2). These factors often necessitated definition of Bowmans plies on the basis of relatively subtle petrographic changes, such as alternating wood-rich and wood-poor horizons within facies I intervals.

## 7.2 PLY STRATIGRAPHY OF THE LOCHIEL DEPOSIT

Thirteen coal plies have been recognised within the three seams of the Lochiel sequence and in ascending stratigraphic order are designated H-1 to H-2 (H Seam), G-1 to G-6 (G Seam) and F-1 to F-5 (F Seam). Ply attributes are summarised in Table 7.1 and Figures 7.1 to 7.5.

Table 7.1 Ply stratigraphy of the Lochiel Deposit

| Ply | Facies / Sub-facies * | Occurrence & Thickness | Differentiation & Distinguishing Features |
|---|---|---|---|
| F-5 | III | Widespread, but best developed in north, 0.2-2.5 m | Very distinctive - Dark, well gelified, wood free. Low tissue abundance, well preserved aquatic liptinites. |
| F-4 | IVa | Widespread, but sometimes erratic. Approx. 0.1-0.2 m thick and undulating | Very distinctive - Hard, dark, angular fragments within a silty matrix. |
| F-3 | Ib, (IIa, III) Locally transitional | Erratic and upper part commonly removed. Rarely exceeds 0.5 m. | Moderate - Earthy to very earthy intervals between two distinctive horizons. |
| F-2 | IIb | Well developed and dominant F Seam ply, 0.5- 2.5 m | Very distinctive - Very fibrous, dark, low wood. Very high cell preservation and high groundmass telovitrinite. |
| F-1 | Ib, (Ia) | Widespread, approx. 0.5 m, grades laterally into carbonaceous sand | Moderate to distinctive - Low wood, earthy to moderately fibrous. Poor gelification, terrestrial liptinite. |
| G-6 | South - Ia (Ib, IIa, IVa, IVb) North – Ic (Ib) | Significant variability with thickening to south (3 m) and north (1.5 m). Absent in central area. | Moderate to distinctive - Considerable variation. Wood- and mineral-rich in south. Pale, very rich in liptinite in north. |
| G-5 | IIb | Relatively consistent, 0.5-1 m, occurring over full area. Local thickening in south to 1.5 m | Very distinctive - Dark, very fibrous, low wood, elevated inertinite, low liptinite, aquatic liptinite assemblage |
| G-4 | Ib, (Ia, Ic, IVa) | Relatively consistent, 2 m, local thinning to south | Distinctive - Light to medium brown, low wood. Low gelification, high liptinite and terrestrial assemblage |
| G-3 | IIa, ( Ib, Ic) | Relatively consistent, 1-1.5 m | Moderate to distinctive - Some diversity in characteristics, fibrous, low wood. |
| G-2 | Ia | Widespread, but lensing out in far south, mostly 1-1.5 m | Distinctive – Wood rich, proportion of large fibrous wood increases to the south. |
| G-1 | III/(IIa) Transitional | Restricted to central and northern areas, mostly < 0.5 m. Significant local thickening in SE to 2 m. | Distinctive - Dark and well gelified. Low wood. Low liptinite and aquatic assemblage |
| H-2 | Ib | Relatively consistent , 0.5-1 m | Distinctive - Earthy, low wood, low mineral matter |
| H-1 | Ia | Thickens to the north, from <0.5- 5 m. Grades laterally and vertically into carbonaceous sands. | Very distinctive - Abundant large wood and massive telovitrinite. Mineral matter common |

Key: * The dominant facies or sub-facies is indicated first, with secondary varieties bracketed

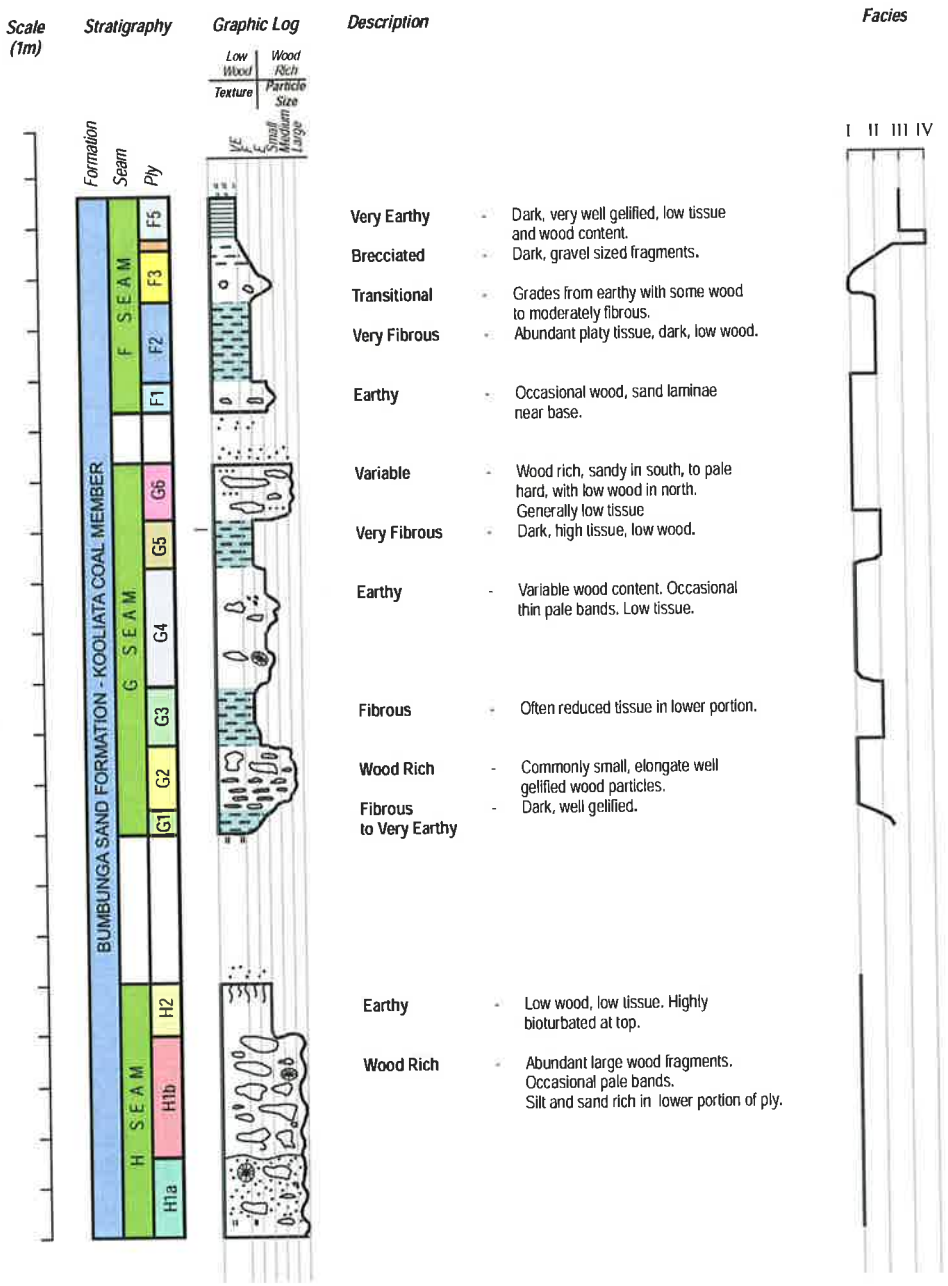



Figure 7.1 Ply stratigraphy of the Lochiel Deposit

### 7.2.1 H Seam

The H Seam contains two plies and consists exclusively of facies I coal. Representing the first major phase of coal accumulation at Lochiel, the H-1 ply grades upwards from carbonaceous sand and consists of a high mineral sub-facies Ia coal. While the inorganic content is significant throughout, mineral matter progressively decreases up sequence. Further sub-division into intervals richer and poorer in mineral matter is possible, although the boundary between them is somewhat indistinct. Coal characteristics are relatively consistent over the ply, being indicative of wood-rich, sub-facies Ia coal with occasional thin

horizons of sub-facies Ic (up to 0.1m) of unknown lateral extent. Ply thickness increases from the southern seam margin, to approximately 4 m in the north (Figure 7.2).

The upper H Seam ply (H-2) comprises sub-facies Ib coal and is clearly differentiated from the underlying ply by a rapid and significant reduction in wood and telovitrinite content. The transition is also accompanied by a reduction in mineral content. This ply is widespread over most of the southern portion of H Seam, with a broadly similar distribution to the H-1 ply. Its thickness is generally between 0.5 and 1 m and is greatest in the south.

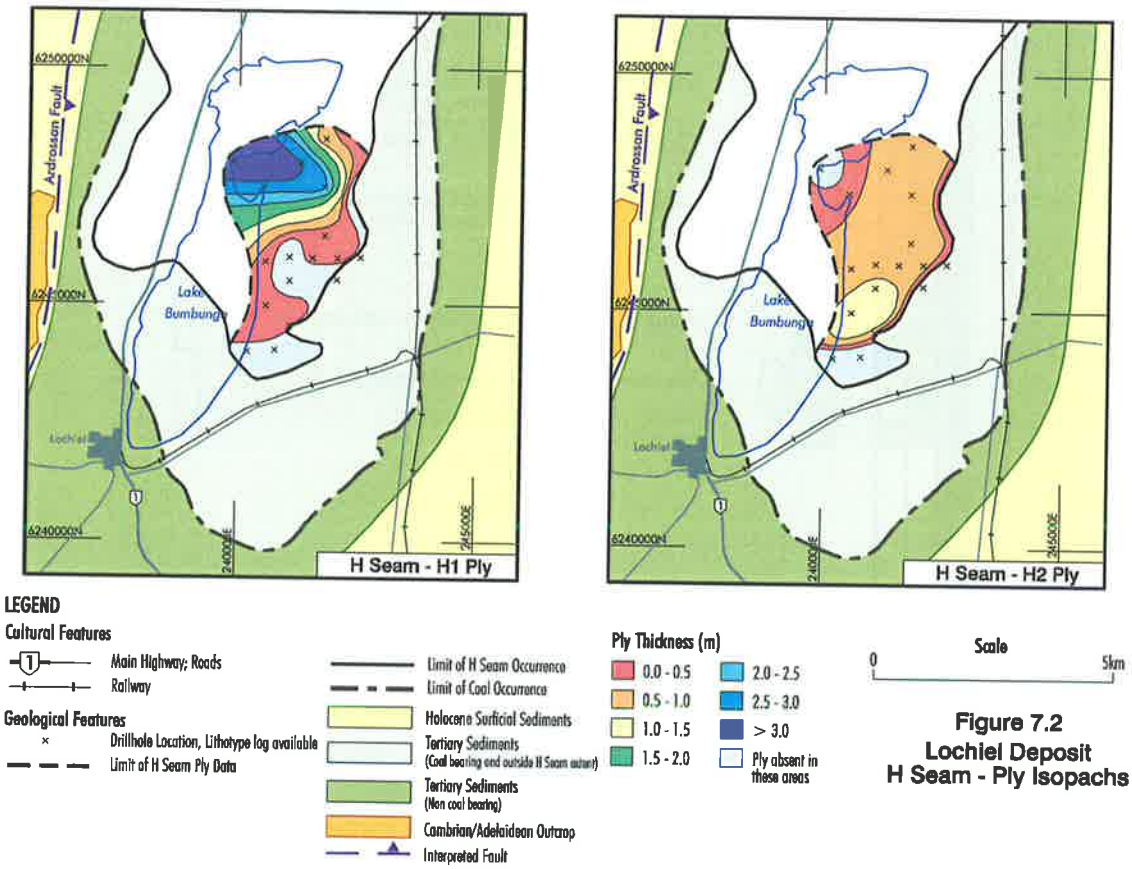



**Figure 7.2**
**Lochiel Deposit**
**H Seam - Ply Isopachs**

### 7.2.2 G Seam

Six plies are recognised in G Seam, comprising coals from each of the four facies groups. Facies I coals are dominant, with considerable facies II representation, minor facies III and rare facies IV.

The basal G-1 ply is a thin and relatively restricted horizon of facies III coal, which is locally upwardly transitional to facies II. It is mainly restricted to the central portion of the study area where a thickness of approximately 0.5 m is attained. However, significant local development exceeding 1 m occurs near the southeastern margin of the deposit (Figure 7.3).

The G-2 ply consists of sub-facies Ia coal and is commonly separated by a gradational boundary (up to ~0.1 m) from the underling ply. Structured tissue consists mostly of possible subaerial wood fragments, although the larger and more fibrous woody component increases to the south. While absent near the southern and eastern seam margins the ply is widespread over most of the study area, averaging ~1 m and thickening to ~2 m in the northwest. Thin horizons (up to 0.1m) of sub-facies Ic, although rare, may develop locally.

A sub-facies IIa coal, representing the first of two G Seam facies II horizons, occurs within the G-3 ply and typically varies from 1 to 1.5 m in thickness, increasing to ~2 m in the north. The distribution of this ply broadly parallels that of the underlying horizon, although lensing out more rapidly on its southern and eastern margins (Figure 7.3). Lateral equivalents in this area appear to be facies I and facies III coals, respectively. The basal portion of the ply is locally transitional into sub-facies Ib, particularly in the central area and contacts to adjacent plies are generally somewhat gradational (i.e. 0.05 to 0.1 m).

The facies I dominated G-4 ply is the thickest within G Seam and is composed mainly of sub-facies Ib coal (transitional to sub-facies Ia near lateral seam margins). The ply extends over most of the study area, averaging ~2 m and showing a slight inward radial increase in thickness (Figure 7.3). In places bands enriched in groundmass tissue are evident and a thin interval showing transitional facies II characteristics is locally developed near the geographic centre of the seam. Some degree of cyclicity due to an upward decrease of groundmass tissue and upward lightening can occur over intervals of ~0.2 m. Throughout the upper portion of this ply up to three, thin bands (i.e. 0.02-0.05 m) of sub-facies IVa occur within a sub-facies Ib groundmass and are best developed in the central north of the study area. However, while the lower band is the most widespread, its occurrence appears erratic and discontinuous.

A distinctive sub-facies IIb coal constitutes the G-5 ply and forms a readily identifiable marker bed (Figure 7.5) that has relatively sharp contacts with adjacent plies. This ply occurs throughout the study area and typically varies in thickness from 0.5 and 1 m, with local thickening to 1.8 m in the south. Partial weathering (and sub-facies IVb development) has occurred in two discrete regions in the south and southeast where G-5 forms the uppermost ply of G Seam. The weathered zone in places extends downwards through the ply (i.e. exceeds 1 m in thickness) and passes gradationally into fresh coal of the underlying G-4 ply.

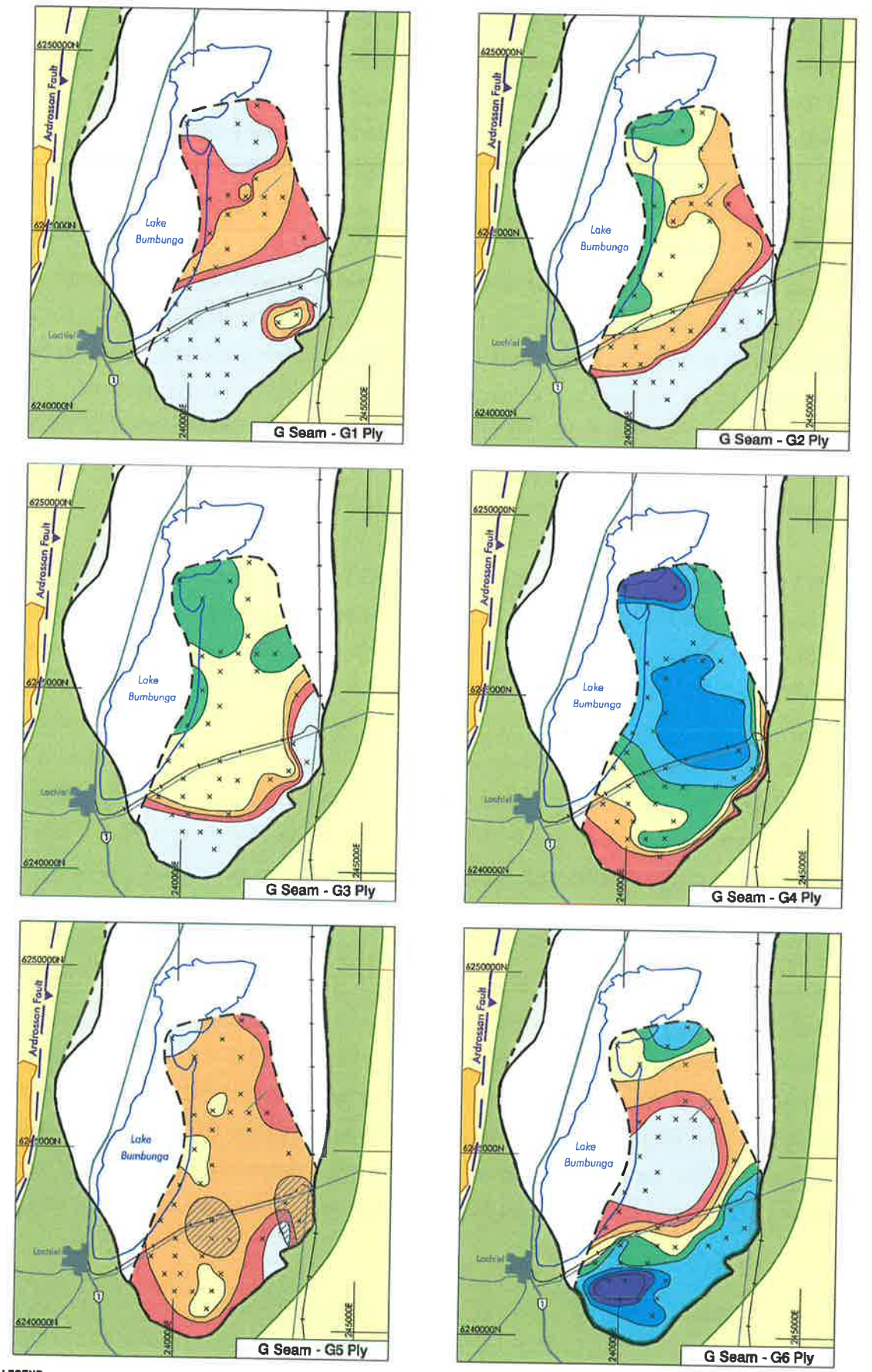



**Figure 7.3**
**Lochiel Deposit**
**G Seam - Ply Isopachs**

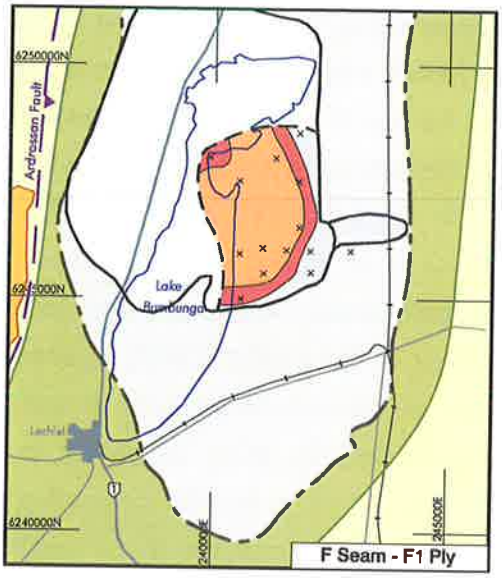
The G-6 ply represents the final phase of G Seam accumulation. While dominated by facies I coal, it varies significantly from south to north and is locally absent in the intervening region. The southern occurrence mainly consists of sub-facies Ia coal which thickens southward to in excess of 4 m. The upper portion is mineral rich (disseminated and weakly laminated, fine to medium grained quartz) and is commonly weathered to sub-facies IVb coal within 1.5 m of the seam roof. Rare thin sub-facies IVa bands (up to 0.2 m) of limited lateral consistency are in places present at the upper ply/seam boundary, or immediately under thin sand interbeds developed near seam peripheries. Immediately adjacent to the southern margin, additional bands develop which in ascending stratigraphic order include sub-facies Ia/Ib, II and Ia/Ib coals. The northern occurrence of G-6 ply is represented by thick sub-facies Ic coal interbedded with sub-facies Ib, its maximum development of ~2 m broadly coinciding with the seam depocentre (Figure 7.3). From here the ply thins and terminates to the south, and grades into sub-facies Ib coal to the east.

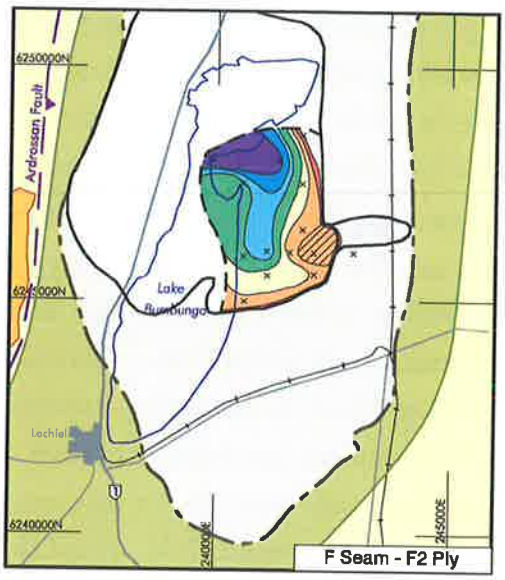
### 7.2.3 F Seam

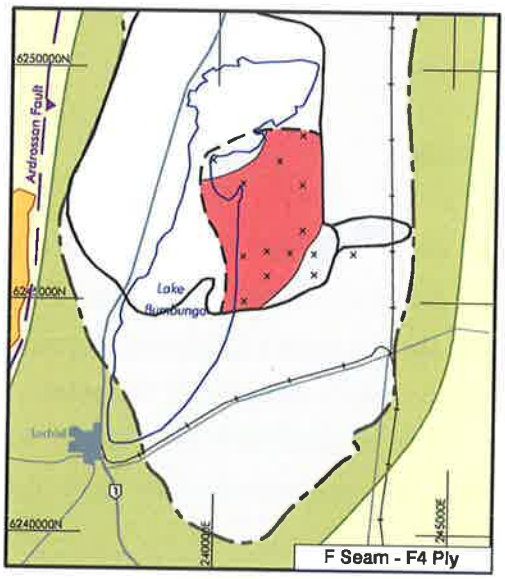
Five plies are defined in F Seam, in which facies II coals are dominant and those of facies I, III and IV relatively minor. The basal F-1 ply typically comprises 0.5-1 m of facies I coal (sub-facies Ib), thickens slightly to the northwest and grades laterally into coaly sand near the southern and eastern margins of the seam. The lower section is distinguished by fine sand laminae, which progressively diminish up sequence. Gelification and liptinite abundance are higher and lower, respectively than levels typical encountered in facies I (see Section 6.2).

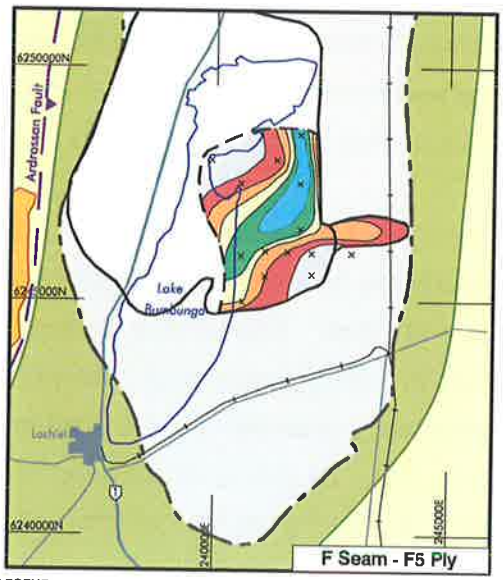
A thick facies II coal (sub-facies IIb) constitutes the F-2 ply, which in turn comprises the bulk of F Seam. The thickness of this ply increases from the seam margins to in excess of 3 m near the seam depocentre (Figure 7.4). Its contacts with the underlying and overlying plies tend to be sharp and the interval represents a readily identifiable marker horizon (Figure 7.5).

The F-3 ply represents the final phase of low mineral coal accumulation in the Lochiel Deposit. While composed mostly of facies I (i.e. sub-facies Ia and Ib), it exhibits a slight tendency toward facies II/III development approaching the roof. This trend is analogous to that near the base of G Seam, where aquatic conditions are more pronounced. The ply is of limited regional extent and in places has been completely removed by desiccation and combustion, resulting the formation of a new ply (viz. F4). Its maximum development of ~1.5 m occurs near the seam depocentre where local thickening and an absence of peat alteration coincide (Figure 7.4).






**LEGEND**

**Cultural Features**

- Main Highway; Roads
- Railway

**Geological Features**

- Drillhole Location, Lithotype log available
- Limit of F Seam Ply Data
- Limit of F Seam Occurrence
- Limit of Coal Occurrence
- Holocene Surficial Sediments
- Tertiary Sediments (Coal bearing and outside F Seam extent)
- Tertiary Sediments (Non coal bearing)
- Cambrian/Adelaidean Outcrop
- Interpreted Fault

**Ply Thickness (m)**

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- > 3.0
- Ply absent in these areas
- Weathered Coal

Scale 0 5km

**Figure 7.4**
**Lochiel Deposit**
**F Seam - Ply Isopachs**

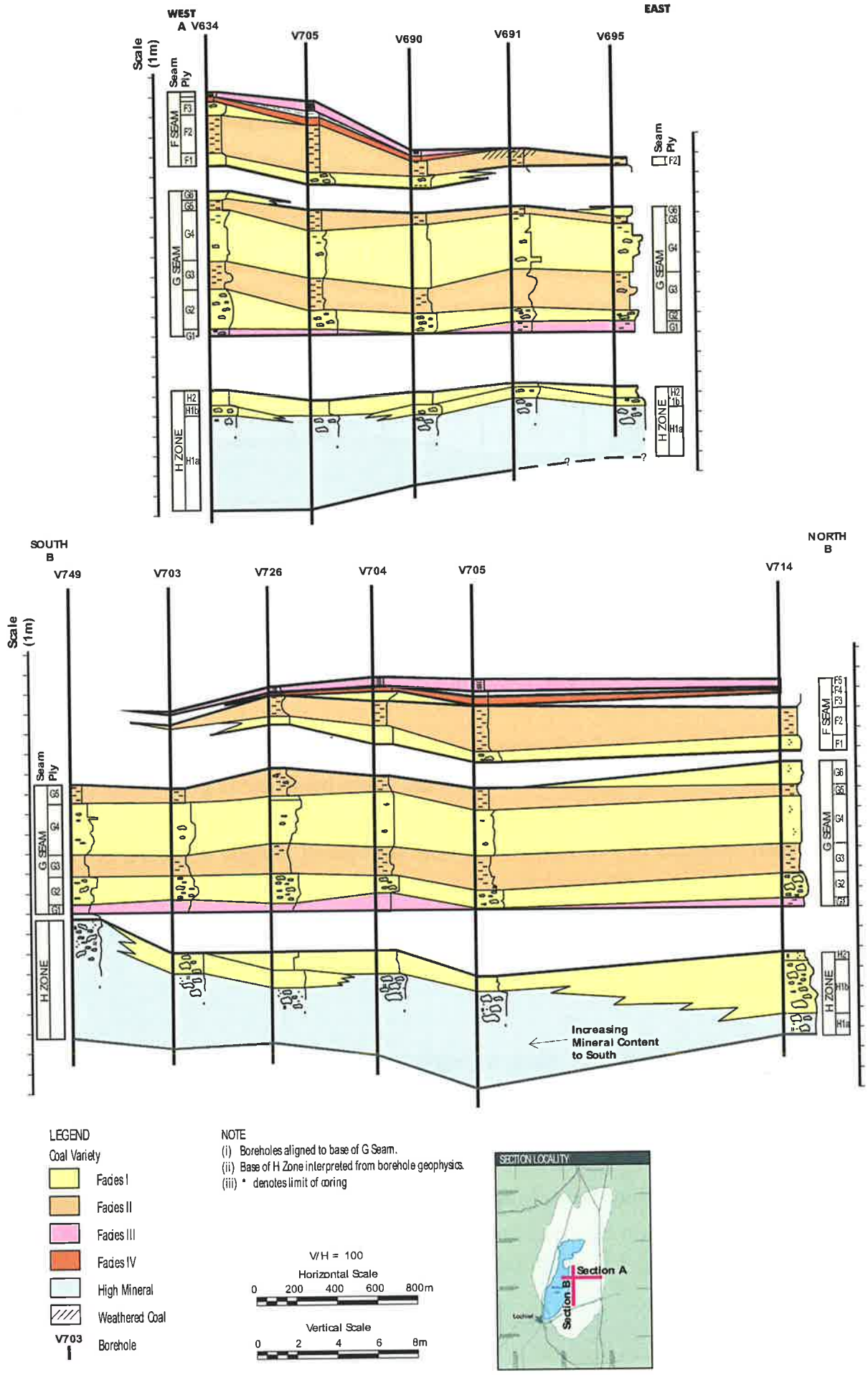



Figure 7.5 Ply correlation through the Lochiel Deposit

Altered sub-facies IVa coal constitutes the F4 ply which, although relatively thin, is very distinctive and readily identifiable. Thickness ranges from 0.1 to 0.35 m and the interval consists of hard, dark, angular fragments up to 20 mm in size, sometimes within a light grey silty matrix. The F-4 ply occurs over a wide area, but is locally very erratic and discontinuous. Furthermore, unlike other plies, its lower boundary is irregular and unconformable with vertical undulations of up to 2 m over lateral intervals of ~10 m (Figure 7.6). Where recognisable, the primary coal characteristics are those of facies II or III, possibly suggesting its derivation from the upper F-3 ply.

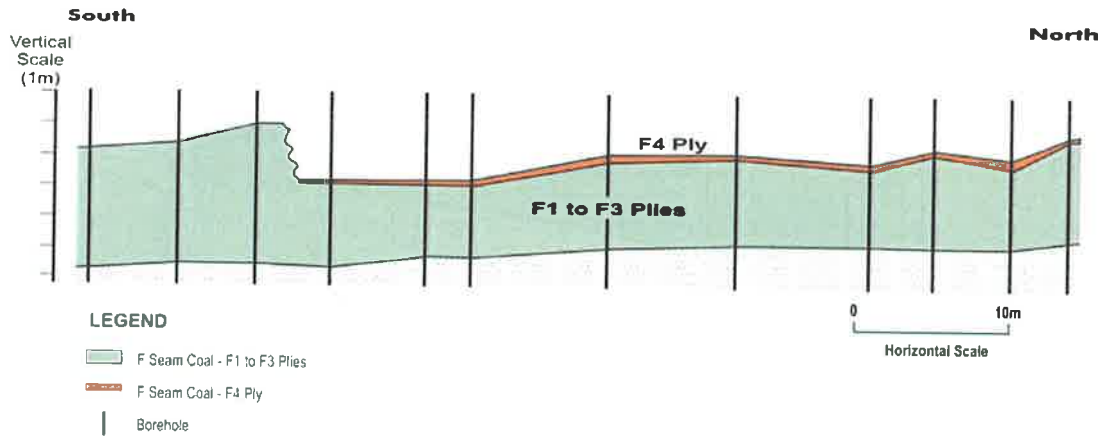



Figure 7.6 Irregular nature of F4 ply

The F-5 ply contains mineral-rich facies III coal and concludes coal accumulation at Lochiel. Its lower boundary is sharply defined while the upper boundary is gradational into highly carbonaceous silts. Its thickness trends contrast with those of the other primary F Seam coals. A maximum thickness of ~2.5 m develops near the eastern margin, while the ply is absent near the seam depocentre (Figure 7.5).

### 7.2.4 Ply boundaries

Ply boundaries vary from very sharp to highly gradational (Table 7.2; Figure 7.7). The sharpest boundaries occur where horizons of sub-facies IVa coal are preserved (i.e. at the roof and floor of the F-4 ply), while facies II/I contacts are also distinct, especially where sub-facies IIb is present. The latter variety occurs at a number of interfaces including F-2/F-1 and G-5/G-4 (facies II overlying facies I) and G-6/G-5 and F-3/F-2 (facies I overlying facies II), with the former grouping being consistently more abrupt. The boundaries between sub-facies IIa and facies I (e.g. G-4/G-3 and G-3/G-2) are generally slightly more transitional (i.e. over an interval of 0.1-0.2 m).

Table 7.2 Ply boundary characteristics in the Lochiel Deposit

| Ply Interface | Facies * | Boundary Characteristics |
|---|---|---|
| F5/F4 | III/IVa | Very sharp |
| F4/F3 | IVa/Ia | Very sharp |
| F3/F2 | Ia/IIb | Sharp to moderately sharp |
| F2/F1 | IIb/Ib | Very sharp to transitional (up to 0.2 m) |
| G6/G5 | Ic/IIb | Very sharp |
| G5/G4 | IIb/Ib | Very sharp to transitional (up to 0.15 m) |
| G4/G3 | Ib/IIa | Moderately sharp to transitional (up to 0.1m) |
| G3/G2 | IIa/Ia | Transitional to moderately sharp |
| G2/G1 | Ia/Ib>III | Transitional |
| H2/H1 | Ib/Ia | Moderately sharp |

Key: * Facies identified represent the dominant variety within the ply

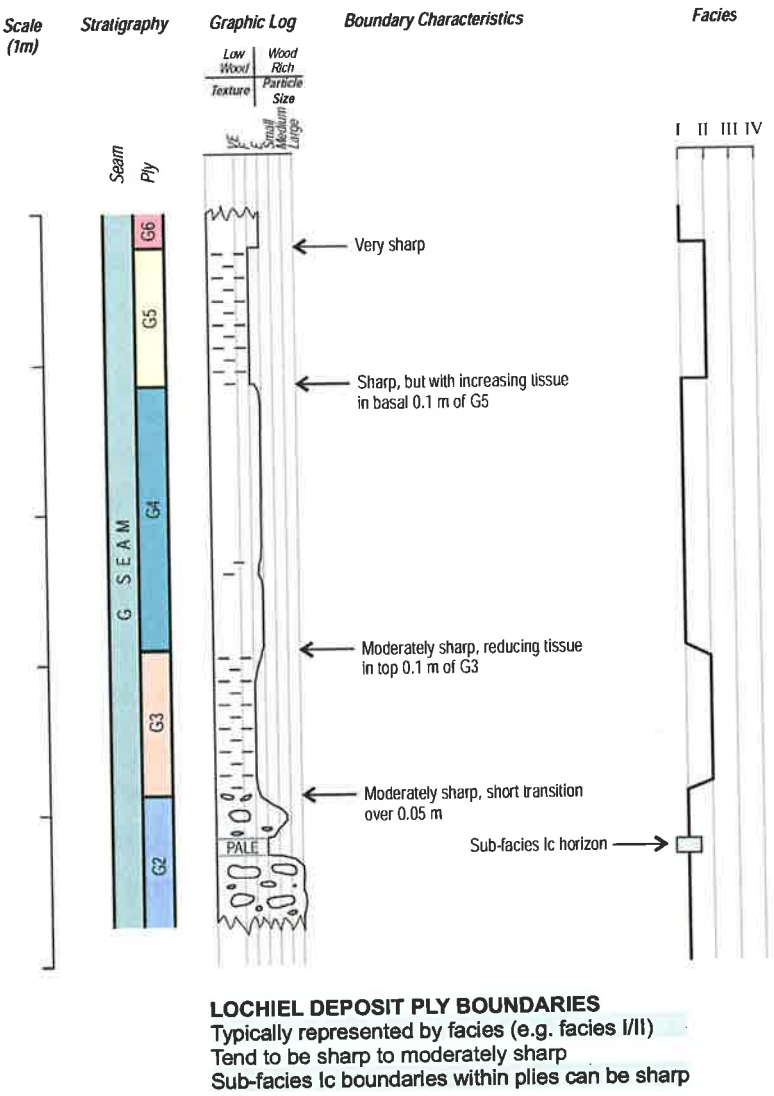



Figure 7.7 Ply boundary characteristics in the Lochiel Deposit

Intrafacies ply boundaries are restricted to facies I where they range from sharp to gradational. Contacts between the H-2 ply (sub-facies Ib) and the H-1 ply (sub-facies Ia) are typically relatively sharp. However, most other sub-facies Ia/Ib boundaries are less consistent. In addition to their inherent character, some of the apparent variability in sub-facies Ia/Ib boundary characteristics may in part reflect the limitations associated with the

detection of irregularly distributed woody fragments in borehole cores (see Section 5.2.2). Sub-facies Ic intervals typically have a transitional base and a sharp upper contact with other facies I coals, especially where developed at the top of upward lightening sequences.

### 7.2.5 Ply correlation

The extent to which plies can be correlated varies according to their facies and location. Facies II coals, in particular sub-facies IIb intervals, represent the best markers and can be readily correlated over considerable distances. Of these, the G-5 ply forms a distinctive band that can be traced laterally for ~7 km (Figure 7.5). The F-2 and G-3 plies also extend throughout most of their respective seams, although the latter ply (composed mainly of sub-facies IIa coal) is somewhat less persistent. Widespread correlation of dark coals (i.e. facies II and III equivalents) and the more problematic correlation of lighter lithotypes (i.e. facies I equivalents) have been reported elsewhere (Hagemann and Hollerbach, 1980; Hagemann and Wolf, 1987; Holdgate *et al.*, 1995) and attributed to regionally extensive elevated groundwater conditions and varying degrees of oxic modification, respectively. Interestingly, at Lochiel, facies III coals (especially those at the base of G seam) are commonly erratic and discontinuous, making them difficult to correlate.

Sub-facies IVa coal of the F-4 ply is another readily correlatable horizon due to its distinctive nature and probable rapid formation in a single event. While of locally erratic occurrence, this ply is widespread and recognisable over a distance of >3 km (Figure 7.5).

Facies I coals are not particularly distinctive and their correlation is usually based on their position with respect to intervening facies II horizons. However, some intervals, such as the sub-facies Ia coal from the G-2 ply (especially where the subaerial woody issue component is dominant) and the sub-facies Ib of H-2 ply, show moderate consistency and can be correlated over distances up to 4 km. In the former, the woody content appears consistent, although this is not universally the case through plies dominated by sub-facies Ia. Some correlation of thicker sub-facies Ic intervals has been achieved, but this becomes more problematic as their thickness decreases.

Ply consistency deteriorates somewhat in the south and towards seam margins, especially in G Seam where several distinct bands are evident in the uppermost ply. In addition, lateral change in coal characteristics is most pronounced in the immediate vicinity of seam margins. In plies of facies I coal, this phenomenon is commonly manifest in elevated contents of wood and mineral matter.

## 7.3 PLY STRATIGRAPHY OF THE BOWMANS DEPOSIT

Sixteen coal plies were identified in the Bowmans Coal Deposit and in ascending stratigraphic order include: C-1 to C-5 (C Seam), B3-1 to B3-7 (B3 Seam) and B1-1 to B1-4 (B1 Seam) (Table 7.3, Figure 7.8).

Table 7.3 Ply stratigraphy of the Bowmans Deposit

| Ply | Facies / Sub-facies * | Occurrence & Thickness | Differentiation & Distinguishing Features |
|---|---|---|---|
| B1-4 | Ia, Ib, (Ic) | Restricted to north, <2.5 m. | Poor to non-distinct, composite interval of wood-rich and wood-poor coals. |
| B1-3 | IIa | Restricted to north, <6.5 m. | Distinctive - Atypical coal. Dark, very low wood, low tissue, reduced liptinite and terrestrial components. High liptinite preservation. |
| B1-2 | Ia | Mainly in the north, <2.5 m. | Moderate to distinctive- Abundant wood and massive telovitrinite. |
| B1-1 | IIa, Ib Transitional | Transitional interval, thins southward from 2 to 1 m. | Moderate - Low wood, moderate groundmass tissue especially in upper portion. Well gelified at base. |
| B3-7 | Ia, Ib | Tentative correlation, 1-2 m. | Poor - Undifferentiated interval of interbedded sub-facies Ia and Ib coals. |
| B3-6 | Ib | Best developed in south and central areas, 0.5-1.5 m. | Moderate – Groundmass tissue-rich zone occurs within the ply, low wood. |
| B3-5 | Ia, (Ic) | Best developed in south and central areas, 0.5-1.5 m. Tentative correlation to north. | Moderate - High wood and large telovitrinite phytoclast content. |
| B3-4 | Ib, (Ia) | Correlation tentative, best developed in north, 1-1.5 m. | Poor - Low wood, low to moderate tissue. Occurs between wood rich horizons. |
| B3-3 | Ia, (Ib) | Correlation tentative, thins southward from 2.5 to 0.5 m. Decreasing wood content to south and up sequence. | Moderate to poor - Wood-rich zone overlying fibrous coal. |
| B3-2 | IIa | Widespread but best developed in north, 0.2-0.8 m. | Very distinctive - Abundant groundmass tissue, fibrous and corky. Large well preserved liptinites and abundant groundmass telovitrinite. |
| B3-1 | IIa | Occurs within a discrete sub-seam. Restricted to north and west of study area, 1 m. | Very distinctive - Abundant groundmass tissue, corky, large well-preserved liptinite. |
| C-5 | Ib, (Ia, Ic) | Widespread, 3-5 m, thins with reduction in total seam thickness. | Poor - Undifferentiated upper portion of the seam. |
| C-4 | Ia | Widespread with slight thickening to south, 1-1.5 m. | Distinctive - Abundant wood and large telovitrinite phytoclasts. |
| C-3 | Ib | Absent in north. Unusually variable thickness, 1-3.5 m, possibly related to poor differentiation. | Poor - low wood, low tissue, low telovitrinite. Occurs between wood-rich horizons. |
| C-2 | Ia , (Ic) | Restricted to where C Seam is well developed, 1-1.5 m. | Moderate - High wood and large telovitrinite phytoclast content. |
| C-1 | II | Patchy, limited to palaeo-depressions, 0.5 m (to 1 m). | Moderate - High gelification, (low liptinite). |

Key: * The dominant facies or sub-facies is indicated first, with secondary varieties bracketed

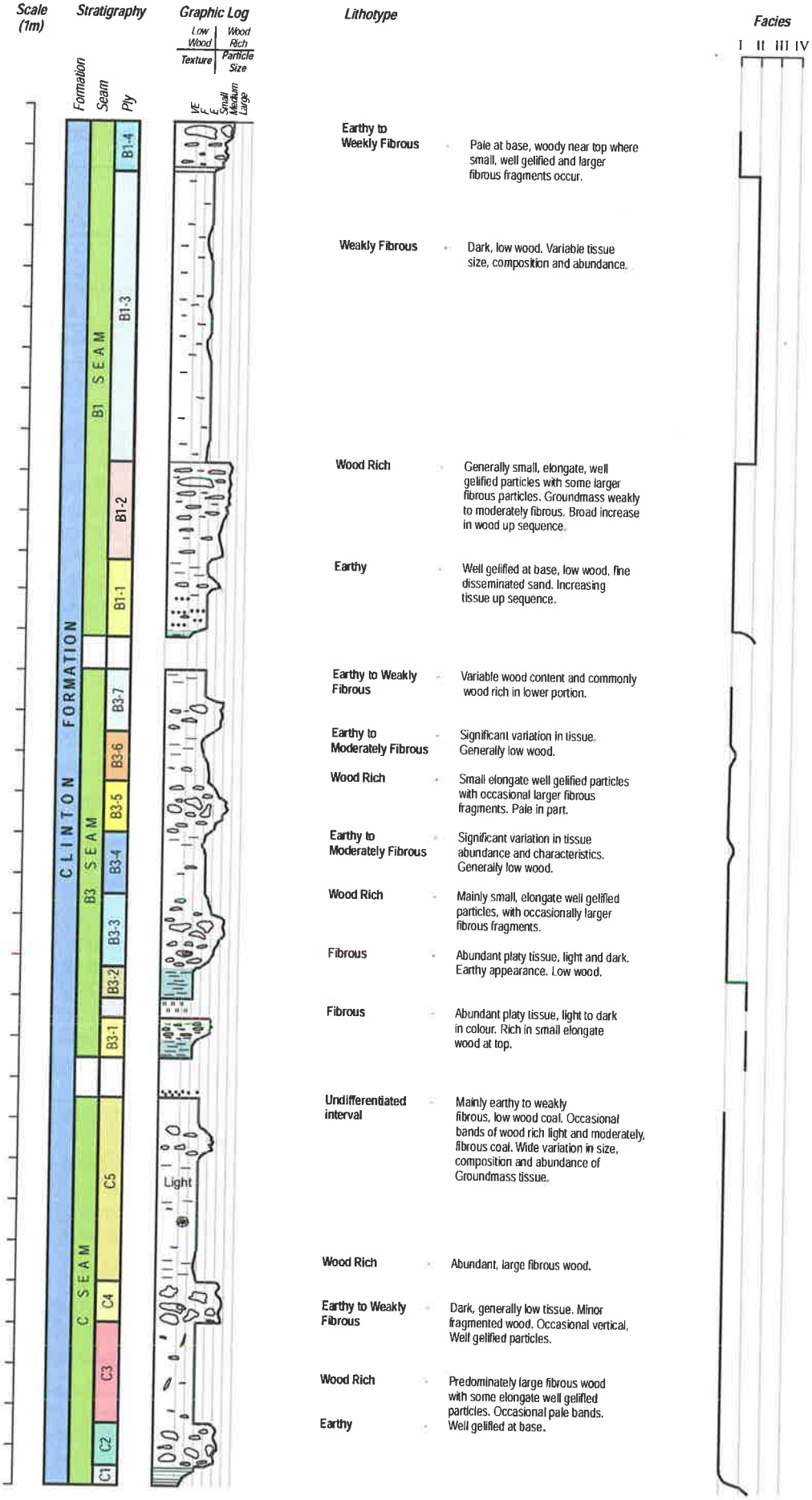



Figure 7.8 Ply stratigraphy of the Bowmans Deposit

### 7.3.1 C Seam

Five plies are recognised in C Seam, most of them facies I coals (mainly sub-facies Ib with some sub-facies Ia). Ply definition and correlation is tentative because of the limited differences between its facies and the northerly and easterly splitting of the seam in the study area.

The basal C-1 ply of facies II coal forms a moderately distinctive ply. It appears to be irregularly distributed and is possibly restricted to local palaeo-depressions at the onset of peat accumulation. Its thickness is variable, with a maximum development of ~1 m in the south.

A wood-rich facies I (i.e. sub-facies Ia coal) comprises the C-2 ply, with occasional thin (0.05-0.1 m) bands of sub-facies Ic coal. It occurs widely (except in the west where it appears to be absent) and its thickness variation (typically 1-1.5 m) parallels overall trends in C Seam. Its lower and upper boundaries are in places sharp and distinct, but they are not consistent.

The C-3 ply comprises a thick and widespread development of facies I (sub-facies Ib coal), and forms the basal section of C Seam in the west (Figure 7.9). Its petrographic characteristics are not particularly distinctive and, as is often the case within thick facies I-dominated seams at Bowmans, ply differentiation is based on the underling and overlying wood-rich horizons. Thickness ranges from 1.5 to 3.5 m and increases to the north and east.

A second wood-rich facies I coal (sub-facies Ia) forms the C-4 ply, with its abundant woody fragments facilitating reasonable correlation. This ply is present throughout the study area where its thickness is relatively consistent (between 1 and 1.5 m), although possibly increasing slightly to the south. Ply boundaries vary from sharp to gradational, with the former being the most common.

The uppermost portion of C Seam is represented by a mixed facies I interval. It consists of mainly sub-facies Ib coal, with some sub-facies Ia intervals in the upper half, although consistent subdivision is not feasible. The ply is widespread and typically 3 to 4 m thick. A mineral-rich zone is commonly present near the base of the ply where thin bands (0.1-0.15 m) of sub-facies Ic may also occur. One of these sub-facies Ic bands has been tentatively correlated over approximately 0.8 km.

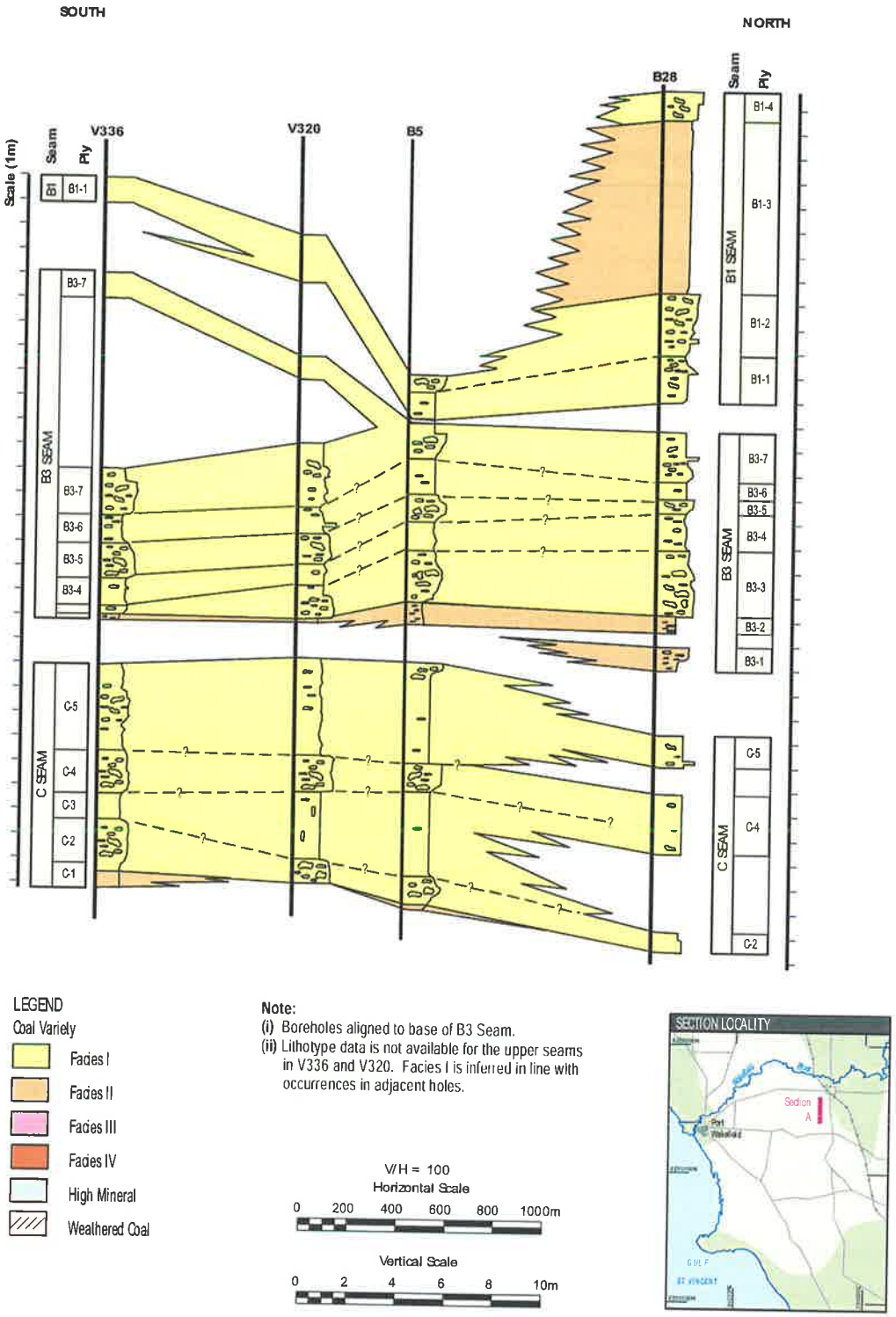



Figure 7.9 Ply correlation through the Bowmans Deposit

### 7.3.2 B3 Seam

Seven plies have been identified in the B3 Seam, most of them comprising facies I coal (i.e. mainly sub-facies Ia and Ib). Limited petrographic variability and the gradational nature of changes in wood and groundmass tissue content generally result in tentative ply differentiation, although two plies of distinctive facies II coal occur at the base of the seam.

The B3-1 ply contains a sub-facies IIa coal (variety IIa-3) and commonly occurs as a discrete sub-seam approximately 0.5 m below the main B3 Seam interval. Petrographically, this ply is readily differentiated by its abundant and banded groundmass tissue and large well-preserved liptinite phytoclasts (see Section 6.3.2.2). The ply is restricted to the northern and western portions of the study area where a maximum thickness of 1 m is attained. An elevated mineral content (macroscopically visible as disseminated fine sand and silt) may occur, especially near the seam's lower boundary.

Sub-facies IIa coal (variety IIa-3) also constitutes the B3-2 ply where it is almost identical in composition and texture to the underlying ply, although extending further south than the B3-1 ply and forming most of the seam floor. Displaying a sharp contact with the overlying facies I coal, it also represents the most distinctive and readily correlated ply within the Bowmans Deposit. Although thin (0.2-0.8 m) the ply is extends throughout the study area and is best developed in the north. Disseminated fine sand and silt are common near its base.

The B3-3 ply marks the onset of persistent facies I formation in B3 Seam and is distinguished by a relatively high wood content. The interval consists primarily of sub-facies Ia coal. Although widespread over the study area, it thins regularly from 2.5 m in the north to 0.5 m in the south, where its correlation becomes increasingly tentative. Parallel to this thinning, the nature and abundance of woody constituents changes, whereby total wood content decreases and smaller well-gelified fragments predominate over large fibrous particles. Gelification is moderate and possibly slightly greater than in other sub-facies Ia coals.

A less distinctive facies I coal (mainly sub-facies Ib), lying between two wood-rich horizons, forms the B3-4 ply. Although its correlation is tentative, the ply appears to persist over the study area, with a thickness between 1 and 1.5 m. Ply boundaries vary from transitional at the base to sharp at the top. Subtle changes in petrographic characteristics are evident, particularly in the concentration of groundmass telovitrinite and the relative abundance and size of liptinites.

The B3-5 ply is the second interval of wood-rich, facies I (i.e. sub-facies Ia) coal within B3 Seam. It is best developed in the southern and central portions of the study area, averaging approximately 1.5 m in thickness. In the north of the deposit, it thins to approximately 0.5 m

and its correlation is tentative. Thin bands of sub-facies Ic coal (up to 0.1 m) are occasionally developed within the B3-5 ply.

An interval of facies I coal (mainly sub-facies Ib) constitutes the B3-6 ply. While its wood content is low throughout, groundmass tissue abundance increases up sequence and varies in size and composition, giving rise to a variety of textures. The ply occurs throughout the study area and appears best developed in the south and central areas, where thickness ranges from 1 to 1.5 m, decreasing slightly to the north.

The uppermost ply of B3 Seam (i.e. B3-7) is an indistinct composite of sub-facies Ia and Ib coals. The lower and central portions of this ply are generally rich in root tissue, especially in the south. Its petrographic characteristics (notably the type and abundance of liptinite and telovitrinite) show some degree of variation, presumably reflecting the composite nature of the ply. Correlation is tentative and its thickness generally ranges between 1.5 and 2 m, with thinning to the west. Thin bands of high liptinite sub-facies Ic coals develop locally.

### 7.3.3 B1 Seam

The extreme lateral variability in the character and thickness of B1 Seam, including its intraseam clastic beds (Figure 7.9) precludes regional correlation of its plies within the study area (see Section 4.3.1.4). Hence, discussion of its ply stratigraphy is based on the sequence and characteristics in borehole B28 located near the seam depocentre. Here four plies of facies I and II coals are defined, ranging in thickness from 2 to 7 m.

The B1-1 ply is a transitional interval, 2 m thick, comprising a thin facies II coal grading upwards into a thicker interval of facies I (i.e. sub-facies Ib) coal. Although the basal facies II occurrence replicates the pattern in underlying seams, its petrographic characteristics (viz. well gelified and telovitrinite poor) differ appreciably from those in the B3 Seam. Disseminated fine to medium sand is common in the lower half of the ply. The B1-1 ply identified in the study area is tentatively correlated with the thin mineral-rich B1 Seam that persists to the south.

A wood-rich band of facies I (sub-facies Ia) coal makes up the B1-2 ply, which attains a maximum thickness of approximately 2.5 m. The interval is reasonably well distinguished by its wood content and abundant, large telovitrinite phytoclasts. The lower boundary is somewhat gradational (reflecting a progressively increasing wood content), while the upper ply boundary is relatively sharp. Petrographically, this ply is similar to sub-facies Ia coals from the underlying B3 Seam.

The B1-3 ply is represented by a thick, distinctive, dark sub-facies IIa-2 coal. With a thickness of ~6.5 m, this ply is the thickest within the deposit, and its boundaries with adjoining plies are relatively sharp.

The uppermost B1 Seam ply (i.e. B1-4) is a non-distinctive composite of facies I coal (mainly sub-facies Ib, but with some sub-facies Ia toward to top). Its total thickness is approximately 2.5 m. A thin (0.1- 0.2 m) interval of unusual resinite-rich sub-facies Ib coal with strong microbanding occurs near the base of the ply.

### 7.3.4 Ply boundaries

Ply boundaries in the Bowmans Deposit vary from sharp to transitional (Table 7.4; Figure 7.10). The most distinctive occur at facies I/II boundaries and in this respect are similar to those in the Lochiel Deposit. However, as a consequence of limited facies diversity, generally poor banding and facies I dominance at Bowmans, sharp distinct boundaries are sparse and the proportion of transitional contacts is greater than in the Lochiel Deposit.

Table 7.4 Ply boundary characteristics in the Bowmans Deposit

| Ply Interface | Facies * | Boundary Characteristics |
|---|---|---|
| B1-4/B1-3 | Ia>Ib/IIa | Moderately sharp |
| B1-3/B1-2 | IIa/Ia | Sharp |
| B1-2/B1-1 | Ia>IIa/Ib | Transitional |
| B3-7/B3-6 | Ia>Ib/Ib | Sharp to moderately sharp |
| B3-6/B3-5 | Ib/Ia | Transitional to sharp |
| B3-5/B3-4 | Ia/Ib | Moderately sharp to transitional |
| B3-4/B3-3 | Ib/Ia | Transitional |
| B3-3/B3-2 | Ia/IIa | Very sharp |
| C5/C4 | Ib/Ia | Transitional to sharp |
| C4/C3 | Ia/Ib | Transitional to sharp |
| C3/C2 | Ib/Ia | Transitional to sharp |
| C2/C1 | Ia/Ib | Transitional to sharp |

Key: * Facies identified represent the dominant variety within the ply

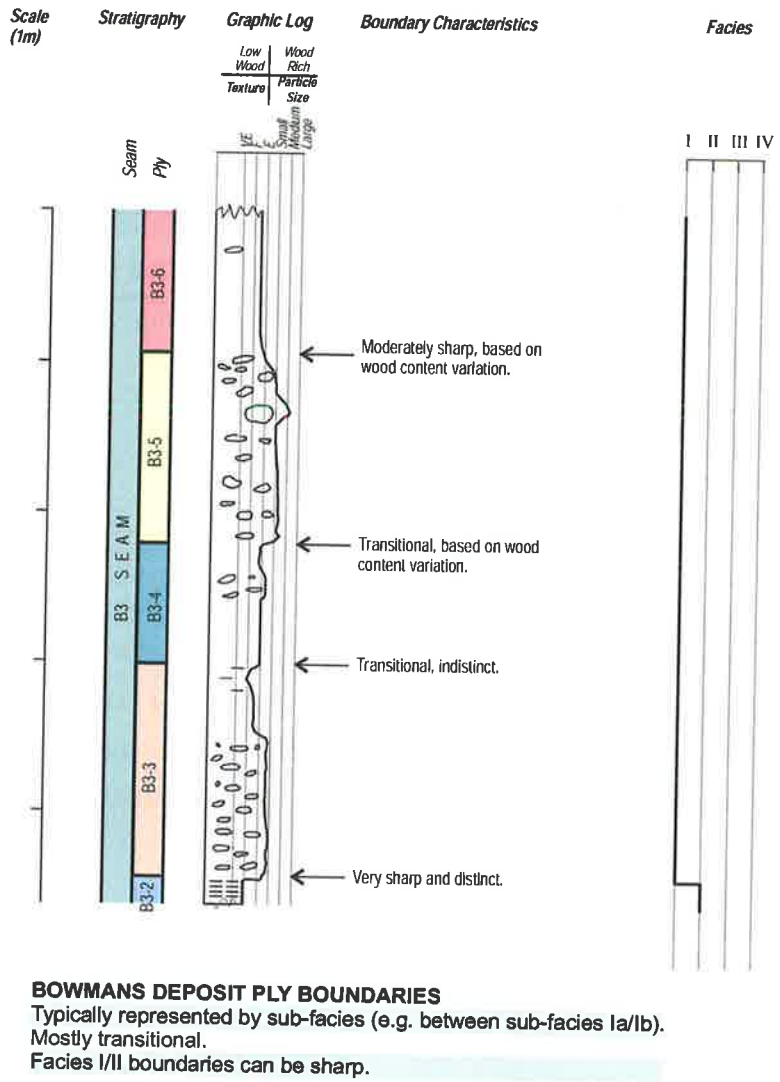



Figure 7.10 Ply boundaries characteristics in the Bowmans Deposit

The most abrupt and readily recognisable ply boundary occurs where basal sub-facies IIa coal from the B3 Seam is overlain by sub-facies Ia coal (i.e. ply B3-3/B3-2). Other facies I to facies II interfaces such as B1-4/B1-3 and B1-3/B1-2 are also relatively sharp, especially the latter where sub-facies IIa coal overlies a wood-rich sub-facies Ia coal (Figure 7.8).

Other boundaries are principally sub-facies Ia to sub-facies Ib interfaces that are commonly defined on wood abundance. These can be locally sharp (e.g. B3-7/B3-6, B3-6/B3-5, B3-5/B3-4, C-5/C-4, C-4/C-3 and C-3/C-2), but are inconsistent and, in places, gradational or indistinct. Elsewhere (e.g. B1-2/B1-1, B3-4/B3-3 and C-2/C-1) they are gradational and hence only tentatively defined.

### 7.3.5 Ply correlation

In general, ply correlation is unavoidably tentative over much of the Bowmans sequence, largely due to the low facies diversity and lower precision of ply definition. However, where facies II coal bands occur, the correlation is more definitive.

The most reliable correlations are those of the B3-1 and B3-2 plies (both facies II) at the base of B3 Seam. The former is developed in the northern part of the deposit and forms a discrete sub-seam, while the latter is more extensive and readily correlated (Figure 7.9). Facies II coal also occurs within the B1 Seam but, although contrasting with the adjacent plies, has not been widely correlated between boreholes because of the aforementioned highly irregular stratigraphic distribution of the B1 Seam (Figure 7.9).

Within the facies I plies, which make up most of the Bowmans coal accumulation, correlation is tentative and based primarily on wood-rich and wood-poor intervals. Furthermore, the precise nature and consistency of the wood-rich zones are unknown and their features are not necessarily unique, or distinctive. However, some wood-rich intervals appear laterally extensive and consistent. A good example is the C-4 ply, which contains abundant large woody fragments throughout the study area.

## 7.4 FACIES OCCURRENCE AND DISTRIBUTION

The architecture of coal facies within the Lochiel and Bowmans Deposits varies considerably, from thin horizons of unknown lateral consistency to thick, laterally extensive intervals. Furthermore, the association of facies changes through the stratigraphic succession, although overall broadly similar patterns are evident in both deposits (Figure 7.11; Table 7.5). Facies I generally dominates seams and is the most abundant over the total coal sequence with other facies decreasing in the order II > III > IV. It is also noteworthy that the relative proportion of facies I coal tends to decrease up sequence.

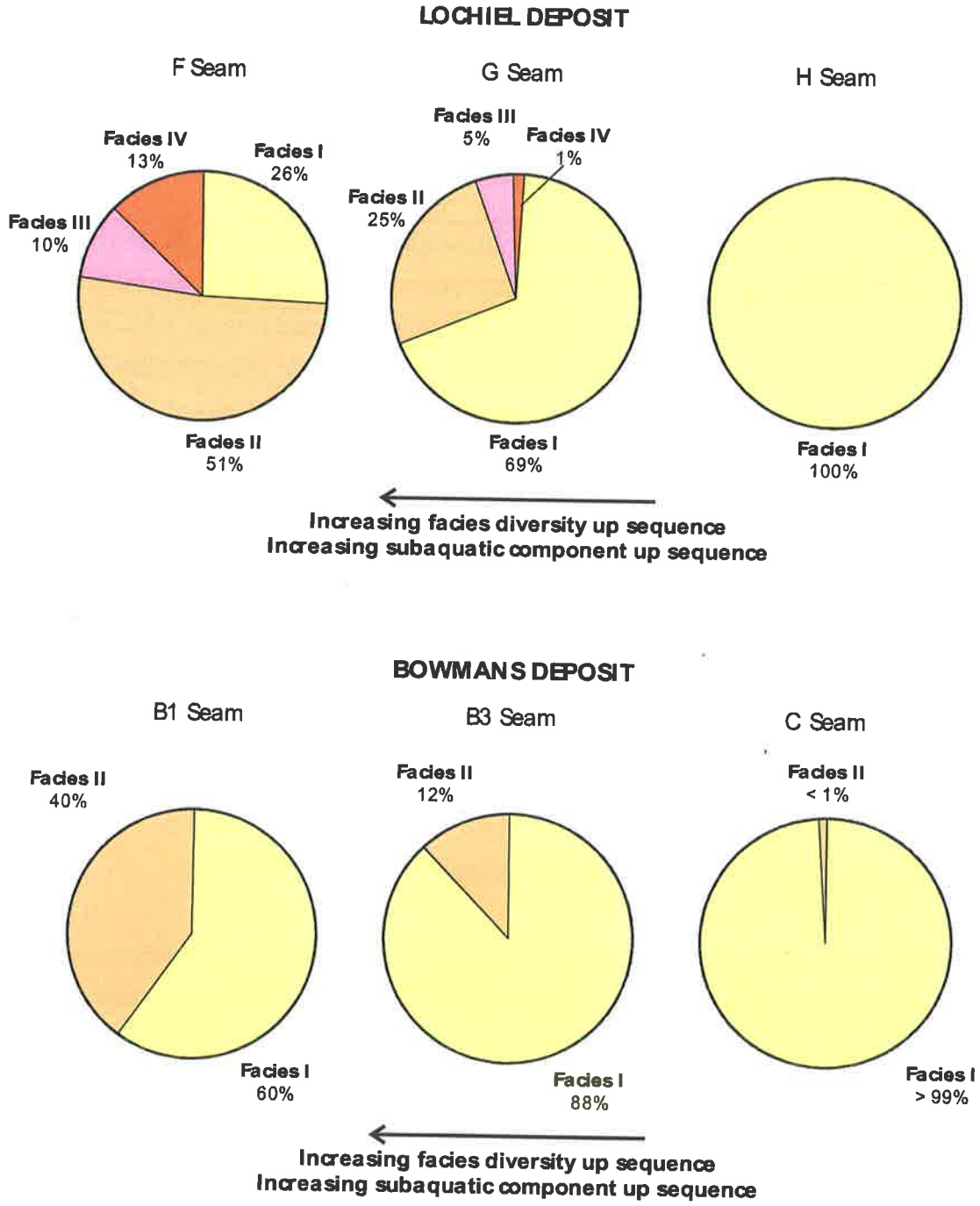



Figure 7.11 Facies distribution by seams and deposit

Table 7.5 Facies and sub-facies distribution by seam and deposit

| Seam | Facies I | | | | Facies II | | | Facies III | Facies IV | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ia % | Ib % | Ic % | I % | IIa % | IIb % | II % | % | IVa % | IVb % | IV % |
| Lochiel | | | | | | | | | | | |
| F Seam | 3.5 | 22.1 | - | **25.6** | 0 | 51.6 | **51.6** | **10.1** | 5.4 | 7.4 | **12.8** |
| G Seam | 30.3 | 33.7 | 4.5 | **68.5** | 13.9 | 11.7 | **25.5** | **4.7** | 0.4 | 0.9 | **1.2** |
| H Seam | 64.4 | 34.6 | 1.0 | **100** | - | - | - | - | - | - | - |
| All Seams | 30.4 | 31.9 | 3.2 | **65.5** | | | **26.5** | **5.0** | 1.2 | 1.8 | **3.0** |
| *Thickness (m)* | *0.2-2.0* | *0.2-2.0* | *0.02-0.2#* | | *0.5-0.75* | *0.5-3.0* | | *0.2-1.0* | *0.1-0.35* | *0.2-1.25* | |
| Bowmans | | | | | | | | | | | |
| B1 Seam | 32.7 | 25.7 | 1.2 | **59.6** | 40.4 | | **40.4** | | | | |
| B3 Seam | 46.9 | 40.3 | 0.5 | **87.7** | 12.3 | | **12.3** | | | | |
| C Seam | 29.3 | 69.0 | 1.5 | **99.7** | 0.3 | | **0.3** | | | | |
| All Seams | 37.2 | 49.2 | 1.0 | **87.4** | 12.6 | | **12.6** | | | | |
| *Thickness (m)* | 0.2-3.0 | 0.2-3.5 | 0.02-0.2 | | 0.5-1 # | | | | | | |

Note: Seams and deposit averages are based on the suite of eight Lochiel and five Bowmans boreholes used for detailed petrographic examination.

Key: # Indicates typical thickness. A significantly thicker occurrence of 1 m occurs near the G Seam depocentre.
Shaded area indicates that these facies are not present at Bowmans

### 7.4.1 Facies I

#### 7.4.1.1 Occurrence

Of the facies I varieties, both sub-facies Ia and Ib can form thick horizons, averaging in the order of 1 and 1.5 m at Lochiel and Bowmans, respectively. However, thicknesses from as low as 0.2 m to in excess of 3 m have been intersected. Bands of sub-facies Ia are slightly thicker overall, and both generally form discrete plies. In contrast, sub-facies Ic coals are mostly confined to thin (0.02 to 0.2 m) intervals of unknown lateral extent, and are generally of insufficient thickness to form mappable plies. An exception occurs near the G Seam depocentre at Lochiel, where an interval ~1 m thick represents a highly anomalous development of this coal variety (George, 1972; Stach *et al.*, 1982; Anderson and Mackay, 1990).

Facies I coals most commonly adjoin other facies I varieties, although contacts with all facies can occur. Sub-facies Ic is most commonly detected within thicker beds of sub-facies Ib coal, and may be present at the top of narrow (0.1-0.2 m) bands in which there is upward lightening and a decreasing groundmass tissue content. At the microscopic scale, thin (~100 μm) bands of sub-facies Ic coal can also occur within sub-facies Ib horizons.

### 7.4.1.2 Distribution

Facies I is dominant in both coal sequences (approximately 65 and 87% of the coal zone at Lochiel and Bowmans, respectively: Table 7.5), occurs in all seams and typically forms the thickest plies. Furthermore, in all but the uppermost Lochiel seam, facies I represents the major coal variety (Figure 7.11).

A phenomenon common to both deposits is an up-sequence reduction in the relative abundance of facies I coals and a corresponding increase in other varieties (Table 7.5; Figure 7.11). This trend is most regular at Lochiel where facies I comprises 100% of H Seam, ~69% of G Seam and 26% of F Seam. At Bowmans, a slight decrease occurs from C Seam to B3 Seam (i.e. almost 100 to 88%), while facies I abundance is reduced considerably in the B1 Seam to 60%.

Of the sub-facies varieties, Ia and Ib are present in all seams, with the latter slightly more abundant (i.e. 30% and 37% for sub-facies Ia, compared to 32% and 49% for sub-facies Ib, in the Lochiel and Bowmans Deposits, respectively; Table 7.5; Figure 7.12). Although widespread, sub-facies Ic is generally restricted to thin bands and represents only 3% of the total coal measures at Lochiel and 1% at Bowmans. Higher levels in the Lochiel Deposit reflect a combination of an anomalously thick interval within the G-6 ply and generally more favourable conditions for its formation. The relative abundances of sub-facies Ic in these northern St. Vincent Basin deposits are comparable with those (1-5%) reported by George (1972) for similar coals in the Latrobe Valley sequence.

Facies I coals are developed at most stratigraphic levels within seams. However, the sub-facies Ic and Ib intervals are least common near the seam base and best developed near the upper seam boundary, especially in geographically central locations. Such occurrence is consistent with reports by Taylor *et al.* (1998) of liptinite-rich coals near the seam roof, with thinning towards the margins. In contrast, sub-facies Ia coals do not appear to show any preferential development with regard to the seam profile, thick intervals occurring in basal, central and upper seam settings.

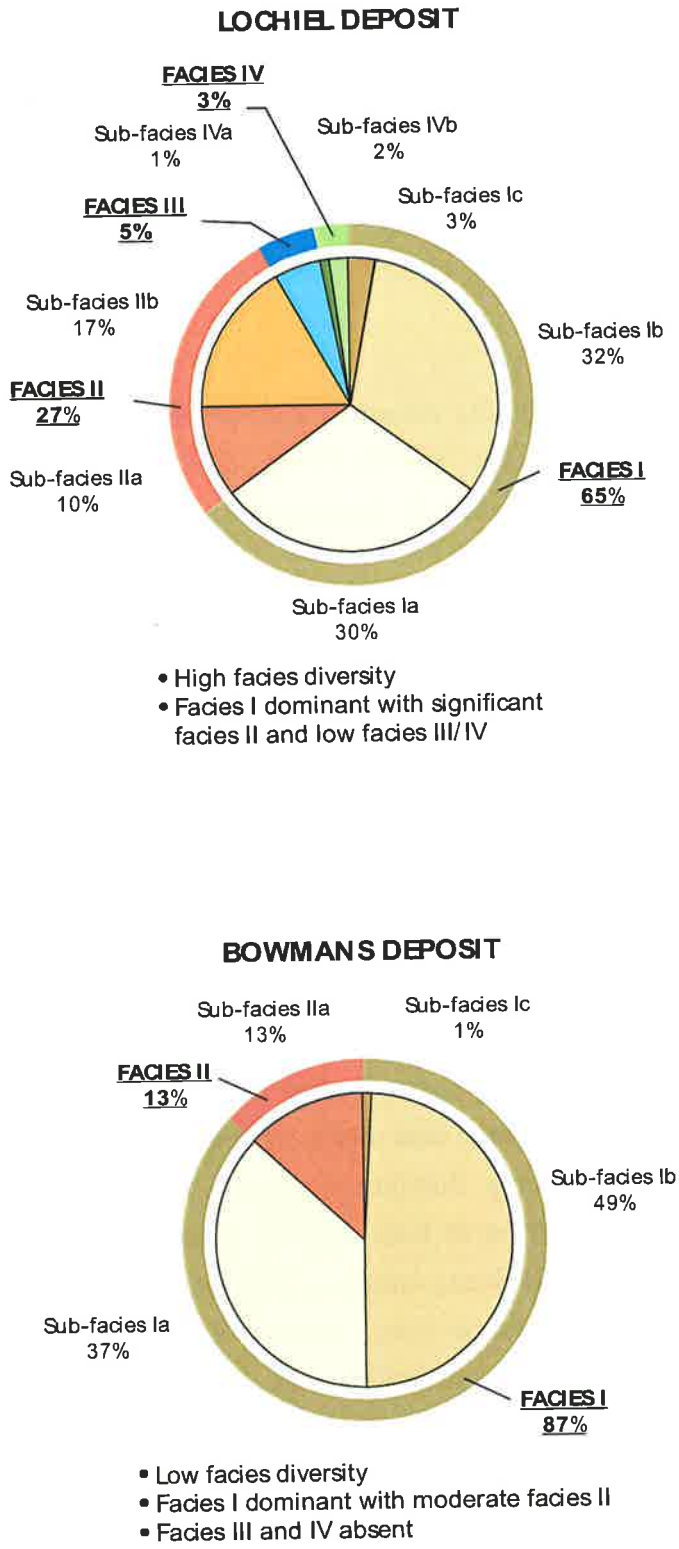



Figure 7.12 Deposit comparison of facies diversity and abundance

Although difficult to quantify, some degree of lateral variability also exists in the distribution of sub-facies Ia/Ib and in the relative wood content throughout the Lochiel Deposit. Other than in H Seam (which consists largely of sub-facies Ia), the proportion of large woody tissue appears to be higher near the deposit margins, than in more centrally located areas. This may also be paralleled by elevated detrital mineral abundance and could reflect preferential growth of forest vegetation in areas of increased nutrient input and lower groundwater levels,

compared to more stunted growth in central areas, as suggested by Esterle and Ferm (1986). Conversely, poorer tissue preservation in the centre of the deposit may be a function of more pronounced ombrogenous conditions, or fluctuating groundwater levels.

### 7.4.2 Facies II

#### 7.4.2.1 Occurrence

Facies II coals are typically laterally extensive and, although in places up to 3 m thick, are generally thinner than facies I plies. Sub-facies IIa coals range from 0.1 to 1 m and average ~0.5 m in thickness, while sub-facies IIb horizons are thicker, ranging from 0.5 to 3 m and averaging ~1 m.

Facies II intervals commonly abut sub-facies Ia and Ib, although in rare instances they may grade into facies III. Contacts of sub-facies IIb with facies I are typically sharp, while boundaries between sub-facies IIa and facies I range from transitional to sharp. The former are most common at Lochiel while a range of contacts exist at Bowmans. Contacts between facies II and facies III coals are typically transitional.

#### 7.4.2.2 Distribution

Facies II coals are considerably less common than those of facies I, especially at Bowmans where they constitute 13% of the total coal measures compared to 27% at Lochiel (Table 7.5; Figure 7.12). Although unevenly distributed through the coal sequence, facies II coal becomes more abundant up-section in both deposits (Table 7.5; Figure 7.11). At Lochiel facies II coals are absent from H Seam, comprise 25% of G Seam and increase to 51% of F Seam, while at Bowmans they increase from <1% of C Seam to 12% of B3 Seam and 40% of B1 Seam. Their relatively high abundance in B1 Seam at Bowmans relates to a single anomalously thick development. The general sparsity and distribution of facies II coals in the northern St. Vincent Basin accords with the findings of Holdgate *et al.* (1995) and Taylor *et al.* (1998) who report that similar varieties of Tertiary brown coal (i.e. dark and charcoal rich) are relatively uncommon in the Gippsland Basin, although they may increase in relative abundance up sequence (Holdgate *et al.*, 2000).

The intra-seam distribution of facies II coals differs between the Lochiel and Bowmans Deposits. Their development at multiple stratigraphic levels is characteristic of the Lochiel Deposit, with departures from this general pattern mainly confined to lateral seam margins. In contrast, thin basal plies of facies II coal are more typical of the Bowmans Deposit, with intra-seam development restricted to the B1 Seam.

Of the sub-facies varieties, the Lochiel sequence is dominated by sub-facies IIb which becomes more prominent up sequence. At Bowmans, facies II is represented only by sub-facies IIa.

### 7.4.3 Facies III

#### 7.4.3.1 Occurrence

Facies III coals occur only within the Lochiel Deposit where they are generally thin (mostly 0.1-0.5 m), although local thickening up to 1 m may occur. Their lateral consistency is unclear and the thicker developments appear to be of limited extent.

Plies of facies III coal occur at the base of G seam and at the top of F seam with the former most widespread. Their occurrence within seams (i.e. between facies I and II horizons) was not detected.

Boundaries between facies III and other primary coal varieties are typically gradational. Interestingly, basal seam facies III to facies I transitions do not necessarily involve an intermediate facies II interval. Contacts with clastic interbeds of highly carbonaceous silt and mineral-rich coal are also generally transitional.

#### 7.4.3.2 Distribution

Facies III coals are relatively uncommon, restricted to either the onset, or near the cessation of peat accumulation and are limited to only two seams, indicating that they form under relatively atypical conditions. Overall, facies III coals constitute approximately 5% of the total seam occurrence at Lochiel and are absent from Bowmans. This distribution is consistent with the findings of Diessel (1992) and Taylor *et al.* (1998) who described associations of sapropelic coals (or coals exhibiting some sapropelic characteristics) and humic varieties, in which the former commonly occupy seam floor and roof settings.

### 7.4.4 Facies IV

#### 7.4.4.1 Occurrence

The occurrence of facies IV coals varies considerably with the nature of peat alteration. Sub-facies IVa coals occur either as thin plies or disseminated throughout gravel-rich bands within

a sub-facies Ib groundmass. In the former, sharp contacts exist with adjoining primary coals (including facies I, II and III coals) and thickness is locally erratic ranging from 0.1 to 0.35 m. Furthermore, the plies can be locally discontinuous and undulate significantly according to the extent of peat desiccation and combustion (Figure 7.6). The second mode of sub-facies IVa occurrence is as very thin horizons (0.02-0.05 m). Three such bands have been recognised over a vertical interval of ~1 m, with the lowest one being the most persistent.

Sub-facies IVb coals do not form discrete, continuous plies. Their thickness ranges from 0.2 to 1.25 m and adjacent to lateral F Seam margins the entire seam can be weathered. Correlation of these intervals is difficult and their regular development is not assured between adjacent boreholes. However, weathered zones appear to extend over lateral distances of ~2 km. Their lower boundaries are gradational into the underlying primary coal. While typically developed in the uppermost portion of the seam, one unusual sub-facies IVb intersection underlies sub-facies Ia coal. In F Seam, sub-facies IVb horizons may overlie sub-facies IVa coal.

#### 7.4.4.2 Distribution

Facies IV coals are restricted to the Lochiel Deposit where they occur mainly in the upper portions of G and F Seam. They are uncommon and constitute only 3% of the total coal interval (Table 7.5; Figure 7.12). However, their precise distribution varies with sub-facies.

Intact bands of sub-facies IVa coal are found near the roof of F Seam and, less commonly, near that of G Seam, while disseminated bands are present in the upper portion of G Seam. It accounts for <1 and 5%, respectively, of the G and F Seams. Sub-facies IVb coal is slightly more abundant overall, although its development is patchy, varying from 1% of G Seam to 7% of F Seam. These coals are restricted to the uppermost portions of seams in the southern part of the Lochiel Deposit.

### 7.4.5 Local palaeoenvironmental inferences

The architecture and stratigraphic distribution of coal facies in the northern St. Vincent Basin throws further light on the nature of its local peat-forming depositional environments. While not specifically definitive, the findings presented herein are in all cases either supportive of, or consistent with, those based on petrographic evidence alone (Figure 6.11).

The dominance of facies I coals (Figures 7.11 and 7.12) and their occurrence in thick plies is consistent with the high accumulation rates suggested for forest peats. Clearly, the normally thin plies of sub-facies Ic coal record atypical conditions, while their greater relative

abundance up sequence reflects the increased potential for development of ombrogenous and/or increasingly aerobic conditions during the latter stage of seam development. The development of sub-facies Ia near seam margins possibly indicates a combination of optimum conditions for growth of luxuriant forest in settings prone to flooding by nutrient-rich waters and enhanced preservation of organic detritus in line with rapid burial by clastic sediment following levee avulsion and overbank incursion.

The wide lateral continuity of facies II (in particular, sub-facies IIb) coals is best explained by elevation of the water table over much of the peat-forming area (i.e. regional scale change in accommodation), similar to features reported by Davies *et al.* (2005) in Cretaceous paralic coals from Utah. Such conditions are most likely to have arisen and/or resulted in settings distal from heavily forested woodlands, thereby severely restricting the input of terrestrially sourced organic detritus. The reduced thickness of these plies (relative to those of facies I) possibly reflects a combination of lesser standing biomass, shorter duration of the necessary groundwater conditions and a tendency to terrestrialisation. An absence of facies II coals from some seams, and the generally sharp boundaries between facies I and II coals, suggests that their formation requires distinctly different conditions. However, since they can be interspersed with other coal facies during seam accumulation, they must represent a normal, albeit distinctive depositional environment.

Facies III appears restricted to particular portions of the sequence (viz. the start and end of peat accumulation) and could be considered atypical within humic coal measures. These coals are thin, erratically developed and uncommon, indicating a combination of unusual peat-forming conditions, low biomass production and restricted occurrence. In concert, these features are consistent with peat accumulation in local topographic lows under permanently open water conditions.

Facies IV coals are rare. Their occurrence and distribution are integral to the postulation of various alteration mechanisms for their formation (see Section 6.6.4). Moreover, weathering of the upper portion of seams in the south of the Lochiel Deposit is consistent with their southerly tilting and exposure as interpreted by Kremor (1986), whereas desiccation and combustion events parallel increasing up-seam differentiation. Burning of the peat to substantial depth occurs locally and erratically, consistent with reports by Rollins *et al.* (1993), and suggests once established fires may persists for prolonged periods, possibly until contact with the water table. The rare occurrence of both varieties (sub-facies VIa and VIb), and their absence from Bowmans, indicates such conditions are highly unusual and confined to the concluding phase of peat formation in the Lochiel Deposit.

## 7.5 EVOLUTIONARY PATTERNS IN LOCAL COAL-FORMING ENVIRONMENTS AND DEPOSITIONAL MODELS

### 7.5.1 Lochiel Deposit

#### 7.5.1.1 Peat accumulation

Facies I (in particular, mineral-rich sub-facies Ia) marks the initial phase of coal formation at Lochiel, suggesting widespread development of topogenous, forest mires over the region, (see Sections 2.4.2 and 6.6.1) with frequent overbank incursion and/or levee avulsion for most of H Seam accumulation (Figure 7.13). However, occasional thin bands of liptinite-rich sub-facies Ic indicate intermittent periods of depositional hiatus and pronounced aerobic degradation, possibly reflecting slight groundwater fluctuations and/or the development of ombrogenous conditions. The dominance of sub-facies Ia may be interrelated to the overbank activity, resulting in nutrient enrichment, luxuriant plant growth and enhanced tissue preservation, accompanied by rapid burial and less prolonged aerobic degradation.

The onset of peat accumulation in G Seam is characterised by the development of open water conditions in restricted and irregular topographic lows, leading to the accumulation of a thin, although somewhat discontinuous basal horizon of facies III (Figure 7.13). However, the remainder of the G Seam reflects alternating terrestrial and semi-aquatic conditions. Variations in groundwater levels associated with this part of the succession appear relatively abrupt and of sufficient magnitude to initiate major changes in flora. In the lower portion of the seam, plies reflecting forest swamps and subaquatic reed and herbaceous dominated mires (sub-facies Ia and sub-facies IIa, respectively) are represented and succeeded by prolonged forest conditions (thick sub-facies Ib coal). In the latter, generally low tissue preservation along with occasional thin sub-facies Ic bands and debris from peat combustion indicate possible ombrogenous conditions and periods of exposure, respectively (Figure 7.13). Two further significant fluctuations of the water table occurred in the upper portion of G Seam resulting in semi-aquatic conditions with extensive marshland development, followed by a rapid relative lowering in water level and a return to forest swamps. However, near the seam depocentre prolonged ombrogenous conditions occurred allowing extreme biodegradation and the formation of a thick sub-facies Ic horizon. In contrast, toward the southern margins increased subsidence resulted in sub-facies Ia and Ib development. Minor peat desiccation and combustion also occurred in the south suggesting some periods of exposure. Facies in G Seam tend to be widespread and laterally consistent, except near its margins where splitting and clastic input is common and ply occurrence more variable.

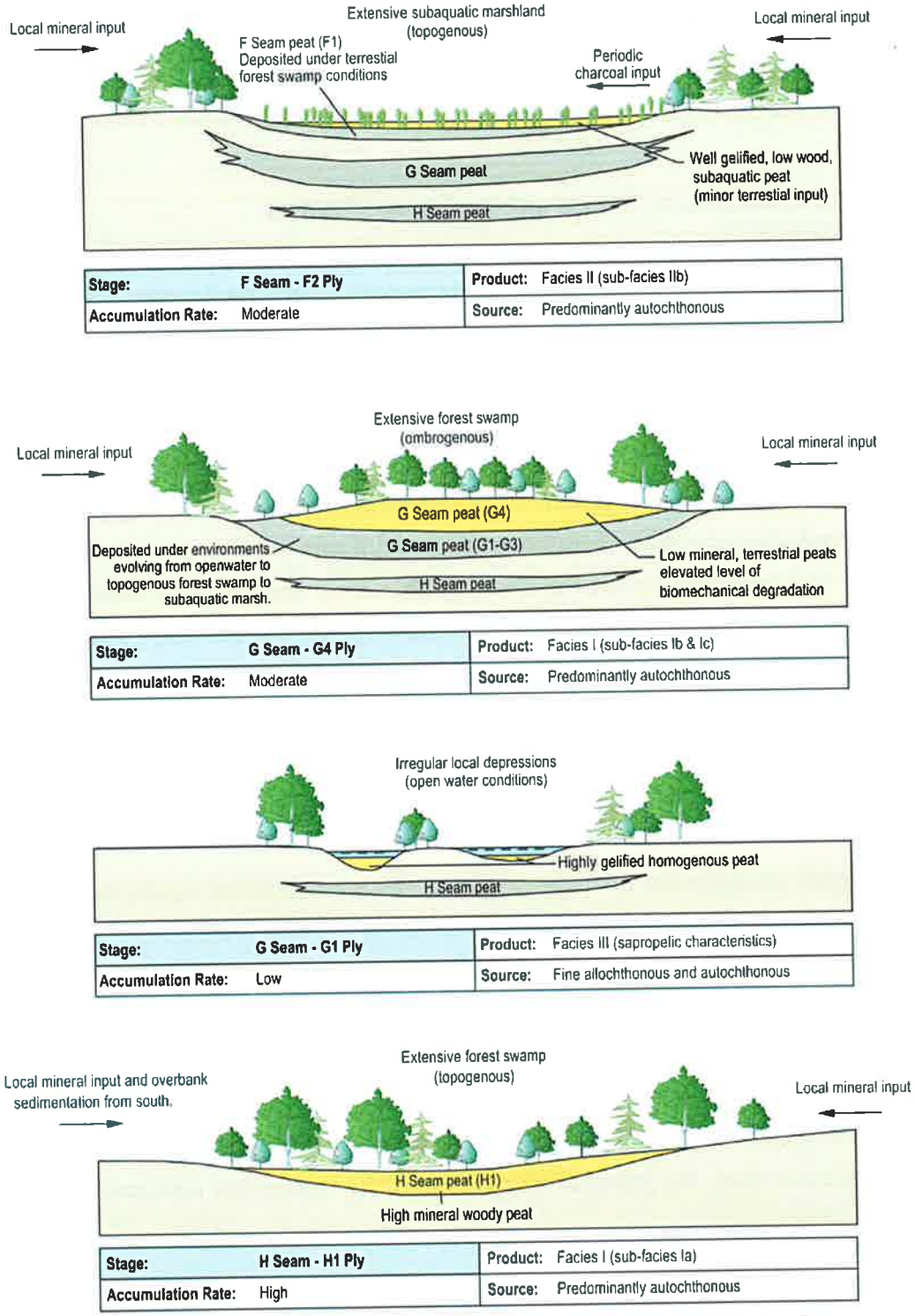



Figure 7.13 Major coal forming stages in the Lochiel Deposit

Following a brief, initial phase of terrestrial conditions with progressively diminishing overbank influence, F Seam is dominated by facies II representing subaquatic marshland environments (Figure 7.13), evolving into open-water conditions (facies III) and ultimately lacustrine clastic deposits, indicating a generally high and steadily rising groundwater regime. However, during its latter stages frequent groundwater fluctuations occurred, leading to variable peat-forming environments and occasional periods of peat exposure and combustion. The latter results in an irregular and in places topographically low peat surface, and generally

marks the end of humic peat accumulation. Ultimately, open water conditions developed in which mineral-rich, sapropelic peats progressively graded into carbonaceous lacustrine sediments, concluding coal formation at Lochiel.

### 7.5.1.2 Facies arrangement, trends and genetic mechanisms

A distinct evolutionary pattern is evident in the facies comprising the three-seam sequence of the Lochiel Deposit, indicating that different conditions prevailed during each successive phase of peat accumulation. The facies I coals of the basal H seam, with its significant but upward diminishing siliciclastic input, evolve into the interbedded facies I and II coals of G Seam, which in turn gives way to the mostly facies II (grading into facies III) coals of F Seam (Figure 7.11). Furthermore, the frequency of intermittent facies IV development increases up sequence. Coal characteristics therefore change from terrestrial humic, through alternating semi-aquatic and terrestrial humic varieties, to ultimately semi-aquatic humic evolving into open water coals displaying some sapropelic characteristics, respectively. The overall pattern is suggestive of increasing facies differentiation with time, superimposed on a trend of progressively rising groundwater levels and accommodation space. Changes in clastic sedimentation also parallel this trend, whereby fluvial-dominated deposition prior to H Seam is replaced by lacustrine conditions at the close of F Seam formation.

The stratigraphic arrangement of facies in G Seam, and to a lesser extent in F Seam, while reflecting an overall trend of a rising water table, is cyclical with several rapid reversals, followed by limited periods of relative stability. As a result, forest and/or ombrogenous coal may overlie semi-aquatic or aquatic varieties (and vice versa), as also noted elsewhere (Teichmuller, 1989; Anderson and Mackay, 1990; Diessel *et al.*, 2000; Mavridou *et al.*, 2003). This variability is highlighted by G Seam, which in isolation could be interpreted as recording an evolution from isolated aquatic settings, to forest swamps and ultimately oxic ombrogenous conditions, the latter albeit punctuated by occasional subaquatic episodes and brief periods of exposure.

Increasing coal differentiation up sequence is paralleled by variations within each facies group. This is best illustrated by the facies II plies. Absent from H Seam, they first appear in G Seam as sub-facies IIa coal (i.e. transitional to facies I), but show progressively more distinctive features up sequence and ultimately occur in F Seam as a thick interval of sub-facies IIb. The aforementioned pattern corresponds with the increasing thickness of each successive facies II ply and a decreased input of terrestrial organic detritus. The distribution of facies I also accords with this phenomenon, the increased development of sub-facies Ib and Ic up sequence reflecting the greater degradation of their terrestrial plant remains.

The development of multiple, laterally extensive plies, accompanied by significant vertical differences in coal characteristics are indicative of major changes in groundwater level during peat accumulation and a regional change in accommodation over the sub-basin. Movements of the order of 1 m are possibly sufficient for wide-scale modification of flora and facies (Diessel, 1992). Sharp ply boundaries, particularly the upper contacts of facies II horizons (with overlying facies I coals) are suggestive of rapid changes in groundwater level and are consistent with local tectonic activity. Movement along the Ardrossan and Whitwarta Faults would have exerted a strong influence on the restricted Lochiel sub-basin and is here inferred to be the primary modifier of groundwater conditions in the region. However, the occurrence of ostensibly ombrogenous peats also suggests some autosedimentary influence over coal characteristics during periods of relative tectonic stability.

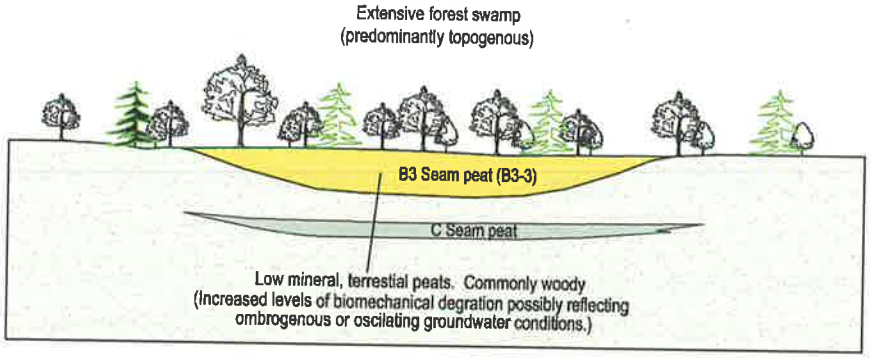
The composition and arrangement of coal facies through the sequence suggests irregular, episodic tectonic activity. However, a broad trend from stable in H Seam, to increasing frequency of fault movement throughout the deposition of G Seam and F Seam (where a number of significant and closely spaced movements occur) is inferred. Within the overall trend of inundation, periods of exposure, combustion and intense aerobic degradation intermittently occurred and were most pronounced late in the coal accumulation cycle. These patterns, while appearing somewhat contradictory, could reflect a combination of diminishing frequency and increasing magnitude of movement along the controlling structures.

### 7.5.2 Bowmans Deposit

#### 7.5.2.1 Peat accumulation

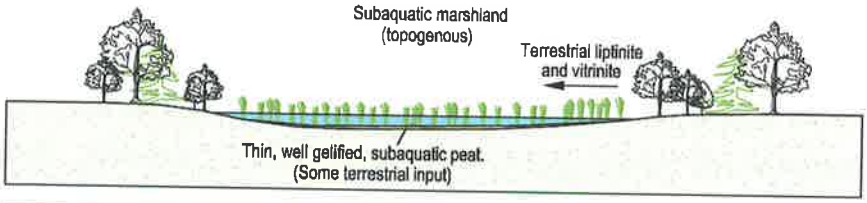
The onset of major coal deposition at Bowmans appears to have involved a brief period of peat accumulation under an elevated groundwater regime, resulting in a basal facies II horizon in C Seam (Figure 7.14). However, the environment evolved rapidly into low lying swamps suitable for forest vegetation, which once established persisted throughout the seam, resulting in a thick facies I horizon. Slight variations in maceral composition and tissue preservation, combined with the presence of thin sub-facies Ic horizons, probably reflect subtle changes in local groundwater levels and/or flora.

Short-lived subaquatic conditions, followed by a relatively uniform and long-lasting terrestrial forest swamp environment, are also indicated for the B3 Seam and resulted in thin basal facies II and thick facies I intervals, respectively. Following its terrestrialisation, the environment appears to have varied only slightly, as evidenced by minor changes in the precursor organic matter and its level of biodegradation through the seam (Figure 7.14). Sub-facies Ic bands are uncommon, suggesting that there was a relatively consistent relationship between the peat and groundwater surface.




| | | | |
|---|---|---|---|
| **Stage:** | **B3 Seam - B3-3 Ply*** | **Product:** | Facies I (sub-facies Ia & Ib) |
| **Accumulation Rate:** | Moderate to high | **Source:** | Predominantly autochthonous |

* Characteristic of much of Bowmans seams away from the seam base.




| | | | |
|---|---|---|---|
| **Stage:** | **C Seam - C1 Ply*** | **Product:** | Facies II (sub-facies IIa) |
| **Accumulation Rate:** | Low to moderate | **Source:** | Autochthonous with some allochthonous |

* Characteristic of basal seam conditions at Bowmans.

Figure 7.14 Major coal forming stages in the Bowmans Deposit

An initial phase of subaquatic peat accumulation, succeeded by relatively consistent forest swamp conditions, is also recorded in B1 Seam (viz. a thin basal facies II horizon overlain by thick facies I coal). However, unlike the underlying seams, it records a distinct intra-seam elevation of the water table that resulted in thick facies II development. While sufficient to preclude larger woody vegetation, the change appears to have had a limited impact on the general composition of the source material, with terrestrial (possibly hypautochthonous) constituents remaining dominant. The final phase of B1 Seam peat accumulation reflects a return to more typical forest swamp conditions.

### 7.5.2.2 Facies arrangement, trends and genetic mechanisms

The coal sequence at Bowmans has a relatively static arrangement of facies, with only limited change between C, B3 and B1 Seams. Peat accumulation commenced under subaquatic conditions in each seam, when low-lying areas were filled by mainly fine organic matter, resulting in thin facies II horizons. Following their terrestrialisation, these depocentres were succeeded by extensive topogenous forest swamps (although in places possibly grading to ombrogenous conditions) where thick facies I peats accumulated. Their limited variability suggests a close balance was maintained between accommodation and peat formation. The uppermost seam (B1) is an exception, with a local return to subaquatic conditions in the

vicinity of borehole locality B28 (Figure 7.9). However, this phenomenon may be related to local conditions associated with extremely thick peat accumulation at this site. The overall pattern of coal distribution throughout the sedimentary sequence in the Bowmans sub-basin is therefore indicative of relatively static conditions of peat accumulation, with a similar facies arrangement repeated in each seam. Overbank sedimentation and/or channel avulsion terminates peat formation in each seam, thereby further highlighting the broad consistency of the depositional regime.

Following establishment of terrestrial conditions, individual seams exhibit only subtle changes in their petrographic characteristics (i.e. liptinite, telovitrinite, wood attributes and wood abundance). Moreover, coals within the typical facies I assemblage do not appear to vary in a systematic, or correlatable, manner. From this, relatively stable conditions and a close coincidence of the water table and the peat surface may be inferred, along with only minor variability of the forest mire. For example, assorted local sub-environments may have developed, but these led to only slight modification of the primary forest biomass and the degree of biomechanical alteration it underwent (i.e. in line with nutrient availability, position of the water table and degree of doming in the mire).

The Bowmans Deposit is characterised by a generally consistent arrangement of facies across its seams and a lack of evolutionary change through its coal succession, and suggest a generally stable groundwater regime. Furthermore, where changes in the water table do occur they are typically minor and, in most cases, insufficient to imply widespread modification of its mire environments. Vertical facies variations appear primarily related to local autosedimentological modification of the depositional setting, in which tectonic and eustatic influences were limited to minimal.

### 7.5.3 Discussion

#### 7.5.3.1 Geological controls on facies architecture

The intraseam and interseam evolutionary trends documented at Lochiel and Bowmans are not unique and have been encountered in widely spaced coal deposits from assorted settings. In paludal depocentres where there is progressive lowering of the water table, aquatic communities typically populate the lowest area of the swamp, to be succeeded by extensive low-lying vegetated swamps and ultimately by doming of the peat (Mackay *et al.*, 1985; McCabe, 1987; Raymond *et al.*, 1987; Cameron *et al.*, 1989; Anderson and Mackay, 1990; Crosdale, 1995; Holdgate *et al.*, 1995; Diessel *et al.*, 2000; Crosdale *et al.*, 2002; Mavridou *et al.*, 2003; Amijaya and Littke, 2005). This scenario would explain the G Seam at Lochiel and, to some extent, each of the Bowmans seams. Situations of progressively rising groundwater evolving from topogenous forest swamp to subaquatic mire and sometimes

ultimately to sapropelic have also been noted (Teichmuller, 1989; Diessel *et al.*, 2000). This appears to have occurred in F Seam and more broadly over the Lochiel coal sequence. Furthermore, the increased degree of differentiation and relative abundance of dark varieties up sequence evident in the Lochiel Deposit (and to some extent at Bowmans) was noted in Rhineland and Latrobe Valley brown coals (Mackay *et al.*, 1985; Kershaw *et al.*, 1991; Holdgate *et al.*, 2000). Findings in the northern St. Vincent Basin coals are therefore consistent with the suggestion of Smyth and Cooke (1976) that evolutionary coal sequences represent a normal part of peat accumulation and provide further examples of this phenomenon in Tertiary brown coals.

Intraseam facies arrangement highlights variations in the relationship between accommodation and peat accumulation within and between seams and deposits, as noted by Diessel *et al.* (2000). Initial terrestrialisation and decreasing accommodation space, followed by a balance between subsidence and peat accumulation, is characteristic of seams in the Bowmans Deposit. In contrast, the ratio of accommodation to accumulation varies significantly within the Lochiel Deposit, from approximately balanced in H Seam, through terrestrialisation and horizons reflecting oscillation between reduced and increased accommodation in G Seam, to a distinctly wetter paludification trend with increasing accommodation in F Seam.

While trends in coal characteristics are evident within plies (tissue and maceral composition), over seams (facies banding) and through the total coal sequence (facies distribution), the upward lightening lithotype cycles as reported in Latrobe Valley coals (Mackay *et al.*, 1985; Anderson and Mackay, 1990; Holdgate *et al.*, 1995) appear poorly developed in the Lochiel and Bowmans Deposits. Their occurrence is restricted to short-lived upward trends of lightening and decreasing groundmass tissue over approximately 0.2 m, whereby sub-facies Ib coals grade into sub-facies Ic and are abruptly terminated by a reversal to sub-facies Ib. The localised depositional settings and, in particular, the periodic groundwater fluctuations at Lochiel, and the generally close match between accommodation and peat accumulation at Bowmans, may account for this difference between the brown coals of the northern St. Vincent Basin and the Gippsland Basin.

The precise mechanisms responsible for changing coal characteristics through seams in the Lochiel and Bowmans Deposits are likely to be complex and multi factorial. The rapid and distinct changes in facies evident within the Lochiel Deposit are attributed to slight tectonic movements along its bounding faults. In the Bowmans Deposit, however, peat-forming conditions appear to have been generally static after the infilling of initial topographic lows and tectonism is unlikely to have played a major role in their origin. Rather, its muted facies changes are considered to primarily reflect local autosedimentary processes. Subtle intra-ply petrographic fluctuations noted in coals from both deposits may involve factors such as doming of the peat surface, with consequent increasing nutrient starvation and acidity (as

outlined by Anderson and Mackay, 1990), sea level variation and climatic change (as postulated by Holdgate *et al.*, 1995) and seasonal fluctuation of the water table (Moore, 1989).

Mechanisms within and external to the depositional system are therefore inferred to account for the evolutionary patterns found in Lochiel and Bowmans coals. In particular, the infill of topographic lows commonly recorded in basal seam intervals and short lightening-up trends within facies I coals were initiated and maintained by sedimentary mechanisms, while rapid facies change and the tendency for increasingly aquatic conditions at Lochiel were driven by external factors and, in particular, tectonic activity. The latter produced the most dramatic intra-seam changes and inter-seam evolution of palaeoenvironments, while the former resulted in intra-seam evolutionary trends.

#### 7.5.3.2 Regional palaeoenvironmental inferences

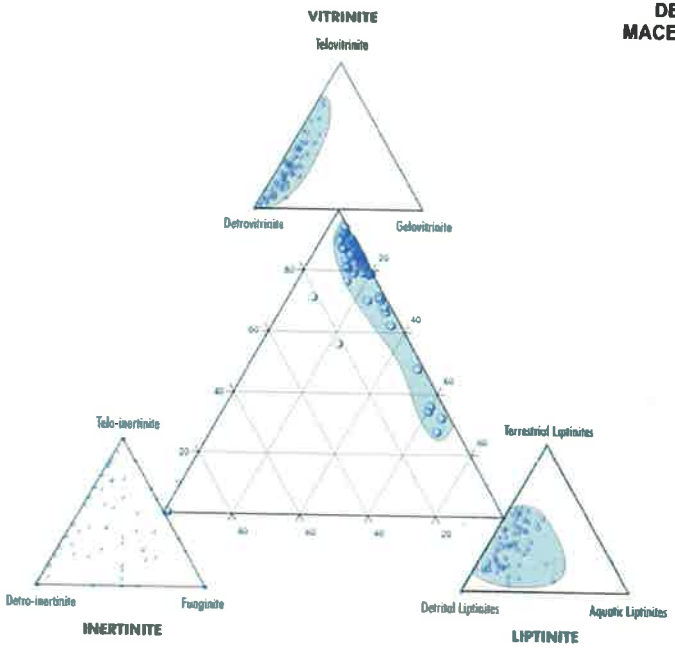
The coals of the Lochiel and Bowmans Deposits differ somewhat with respect to almost every parameter assessed[1] (Figures 7.12, 7.15 and 7.16; Table 7.6). These inter-deposit variations in ply stratigraphy, facies characteristics and intra-seam facies distribution parallel the findings regarding clastic sedimentary environments and gross seam attributes (see Section 4.5.3). Significant differences in regional palaeoenvironmental settings are therefore inferred, with the groundwater table likely to have been a key variable.

The Lochiel Deposit contains a wide variety of facies, is well banded with thin and distinct plies and documents a secular trend towards progressively wetter conditions. In contrast, the Bowmans Deposit has a limited facies diversity in which facies I is dominant. It's seams contain thick, relatively indistinct plies with a generally consistent arrangement of facies that reflects brief semi-aquatic accumulation followed by persistent forest swamp conditions (Table 7.6).

[1] Some qualification of this general finding may be necessary in view of the fact that fewer boreholes were investigated in the Bowmans Deposit.

**Figure 7.15**
**DEPOSIT COMPARISON**
**MACERAL CHARACTERISTICS**

**LOCHIEL COALS**

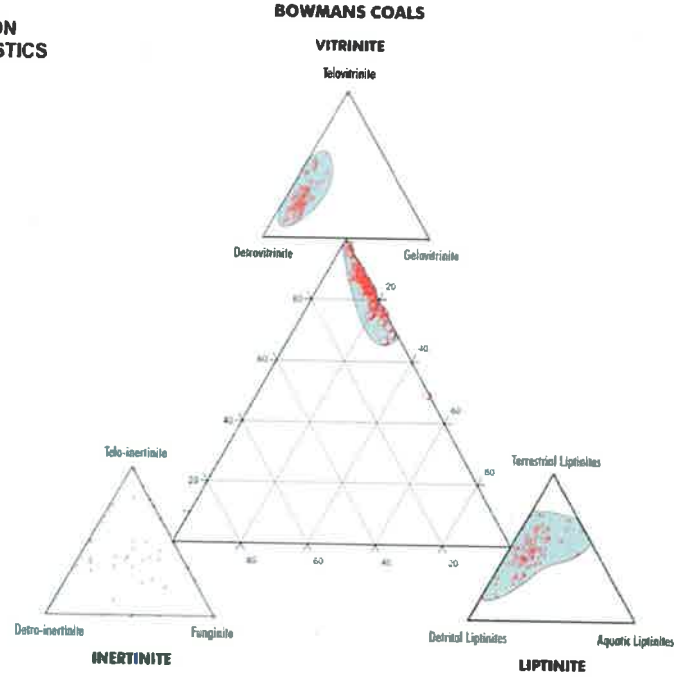



**GELIFICATION INDEX**

**MACERAL FEATURES**

| | |
|---|---|
| VITRINITE ABUNDANCE | High - dominant |
| VITRINITE PRESERVATION | Low to high |
| DOMINANT VITRINITE | Detrovitrinite |
| LIPTINITE ABUNDANCE | Low to very high |
| LIPTINITE ASSEMBLAGE | Terrestrial to aquatic |
| LIPTINITE PRESERVATION | Moderate |
| DOMINANT LIPTINITE | Liptodetrinite |
| INERTINITE ABUNDANCE | Very low to low (high on rare occasions) |
| GELIFICATION | Very low to very high |

**BOWMANS COALS**




**GELIFICATION INDEX**

**MACERAL FEATURES**

| | |
|---|---|
| VITRINITE ABUNDANCE | High - dominant |
| VITRINITE PRESERVATION | Low to moderate |
| DOMINANT VITRINITE | Detrovitrinite |
| LIPTINITE ABUNDANCE | Low to moderate |
| LIPTINITE ASSEMBLAGE | Terrestrial |
| LIPTINITE PRESERVATION | High |
| DOMINANT LIPTINITE | Resinite, suberinite and liptodetrinite |
| INERTINITE ABUNDANCE | Very low |
| GELIFICATION | Low to moderate |

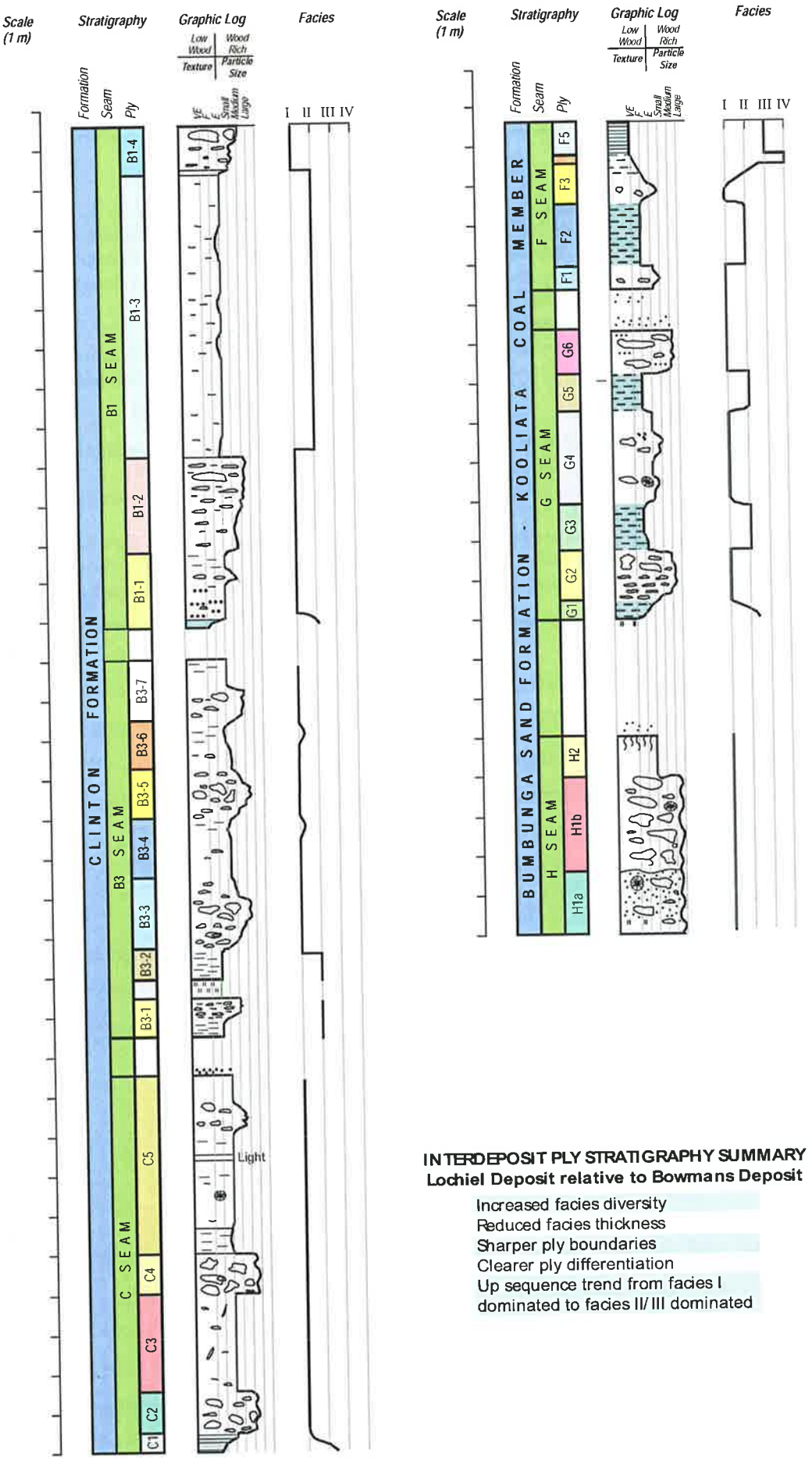



Figure 7.16 Deposit comparison of ply stratigraphy

Table 7.6 Inter-deposit comparison of facies architecture

| Parameter | Lochiel Deposit | Bowmans Deposit |
|---|---|---|
| PLY STRATIGRAPHY | | |
| Differentiation | Good | Poor to moderate |
| Correlation | Good | Poor |
| FACIES CHARACTERISTICS | | |
| Diversity | High<br>6 Primary sub-facies<br>2 Alteration sub-facies | Low<br>4 Primary sub-facies<br>0 Alteration sub-facies |
| Boundaries | Sharp (to gradational) | Gradational (to sharp) |
| Thickness | 0.5–2 m | 2–4 m |
| Banding | Common in G and F Seams<br>Intraseam banding of facies I/II | Rare<br>No intra-seam banding, but repetition of seam pattern through coal zone |
| FACIES DISTRIBUTION | | |
| Upper Seam (F/B1) | Facies II dominated with facies I, III and IV present | Basal facies II with thick facies I and II intervals |
| Central Seam (G/B3) | Banded facies I and II, with minor III | Basal facies II with thick facies I |
| Lower Seam (H/C) | Exclusively facies I | Basal facies II with thick facies I |
| EVOLUTIONARY TREND OVER COAL SEQUENCE | Initially terrestrial, becoming increasingly aquatic up sequence | Mostly terrestrial throughout, with an initial semi-aquatic phase in each seam |

A variable and fluctuating groundwater regime is interpreted for the Lochiel Deposit, with the frequency (and, possibly, amplitude) of oscillation increasing up sequence, leading to a relative increase of accommodation over accumulation. Local tectonic activity, probably involving movement along major north-south-trending bounding faults (Figure 4.1), is likely to have resulted in a variety of peat-forming settings and, thus, to have exerted a strong influence over the distribution of coal facies within the Lochiel sub-basin.

Relatively stable groundwater and local tectonic conditions and an environment in which accumulation and subsidence rates were approximately matched is interpreted for the Bowmans Deposit. In this setting sedimentological controls exert the primary influence over facies development and terrestrial forest swamp environments dominate.

## 7.6 SUMMARY

A well-defined coal stratigraphy has been established for the Lochiel Deposit based on its distinct facies banding, multiple coal types and consistent seam geometry. Ply boundaries commonly coincide with changes in facies and the mean thickness of individual plies is ~1 m. In contrast, facies banding at Bowmans is poorly developed and the correlation of plies tentative, the latter being due to the limited diversity of its facies assemblage, the irregular seam architecture, and the lesser number of investigation sites. Furthermore, the definition of its plies is commonly based on sub-facies boundaries and the plies are thicker, averaging ~2

m. Facies II coals are the most distinctive and readily correlatable in both the Lochiel and Bowmans Deposits.

Facies I coals (especially sub-facies Ia and Ib) are the dominant variety within most seams and typically form the thickest plies. Although thinner, Facies II intervals vary from rare to common and are generally more laterally extensive than facies I coals. Facies III and IV coals are rare. Whereas facies I and facies II coals can occur at a variety of stratigraphic positions within a seam, facies III developments are restricted to basal and near-roof positions and facies IV horizons typically occur at or near the top of the seam.

Evolutionary patterns in facies occurrence are evident in both deposits, although significantly more pronounced at Lochiel where the proportion of facies II (and III/IV) increases up sequence, reflecting increasing differentiation and accommodation, and a tendency to more subaqueous marsh accumulation. However, superimposed on this broad trend are temporary reversals to terrestrial and ombrogenous conditions bracketed by periods of non-deposition and exposure. In the Bowmans Deposit coal type is more consistent throughout the sequence, wherein thin basal subaqueous facies II coal is typically overlain by a thicker and poorly differentiated terrestrial facies I interval. This succession suggests brief elevation of the water table and mire formation followed by its terrestrialisation and creation of a relatively stable forest swamp in which accommodation and peat accumulation were well balanced.

The pattern of facies occurrence at Lochiel suggest multiple, generally rapid oscillations of the water table in a restricted sub-basin, which increased in frequency over time. These groundwater fluctuations were driven by local tectonic activity and were sufficient to cause widespread modification of the local flora and their ecological settings. In the Bowmans Deposit relatively stable groundwater prevailed (possibly with a hydraulic connection to the nearby marine environment), while subsidence and accumulation were well matched in a more extensive and less restricted mire environment. Here autosedimentological processes were primarily responsible for modification of the local environments and seam termination, and the impact of contemporary tectonism was minimal.

# 8 HYDROCARBON BIOMARKERS AND THEIR DISTRIBUTION WITHIN FACIES

Natural bitumens extracted from a representative suite of coals (Lochiel, n = 16 and Bowmans, n = 11; Table 3.3) were analysed for their aliphatic hydrocarbons and, in particular, their terrigenous terpenoids and hopanoids. These components facilitated assessment of the nature and relative contribution from terrestrial plants and bacterial sources, respectively, for each facies and deposit. In this chapter the biomarker assemblage is initially identified and evaluated, the abundance of its major compound classes considered, and the extent of its variation according to facies and deposit examined. Ultimately, the relationships between key biomarker classes are assessed and applied to refine our understanding of the local and regional palaeoenvironments of the northern St. Vincent Basin.

## 8.1 COMPOUND SUITE, OCCURRENCE AND CHARACTERISTICS

Assorted aliphatic biomarkers were detected in the coal suite including *n*-alkanes, sesquiterpenoids, diterpenoids, des-A-triterpenoids, regular triterpenoids, A-ring contracted triterpenoids and hopanoids (Springbett and McKirdy, 1999; Figure 8.1). The assessment of biomarker occurrence, evaluation of compound characteristics and, where possible, assignment of structure was a significant undertaking and in the process a vast amount of geochemical data was generated. A summary of findings pertaining to compound occurrence and characteristics for each major compound class are presented below. A more comprehensive listing of terpenoid compound suites and mass spectra of the major compounds may be found in Appendix D1 and D2, respectively.

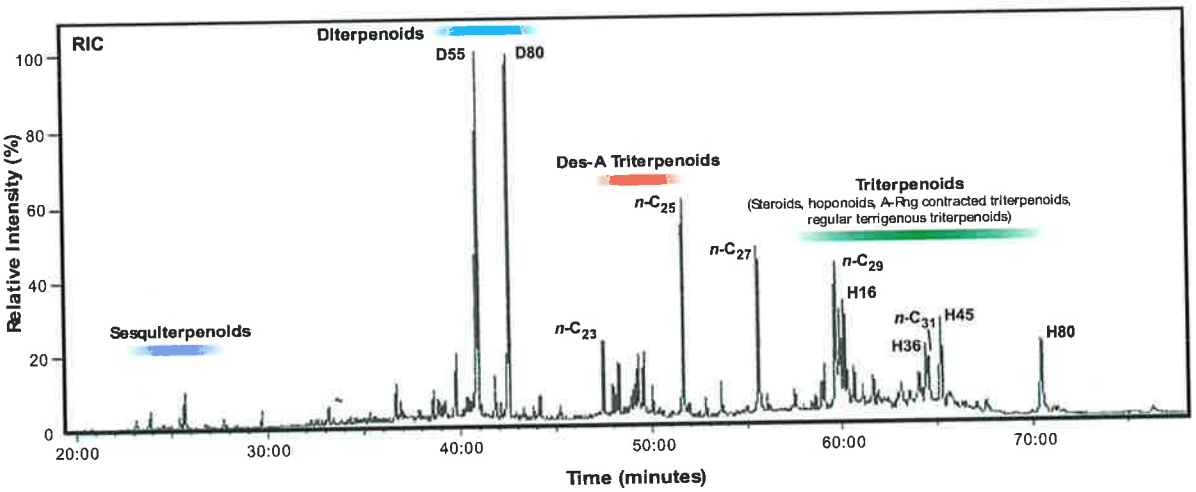



Figure 8.1 Compound classes in the aliphatic fraction

### 8.1.1 Normal alkanes

Normal alkanes represent a significant portion of the aliphatic fraction. Their distribution typically ranges from $C_{21}$ to $C_{33}$ with a maximum at $C_{25}$ and displaying a strong odd to even carbon number predominance (Figure 8.2).

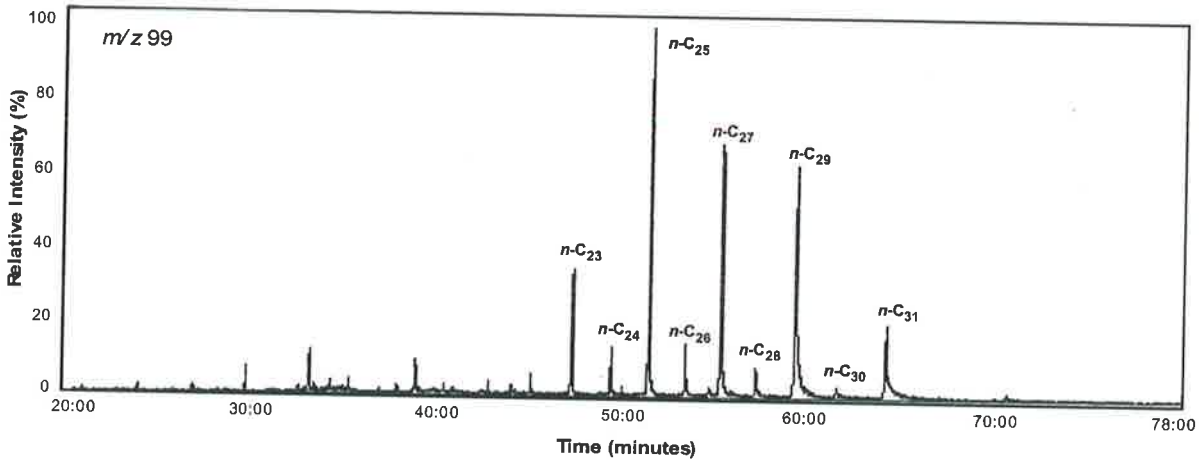



Figure 8.2 Representative normal alkane distribution

The degree of odd/even predominance was quantified using the Carbon Preference Index (CPI), as defined by Chaffee *et al.* (1986):

$$CPI = \left( \sum(n\text{-}C_{23} - n\text{-}C_{31})_{odd} + \sum(n\text{-}C_{25} - n\text{-}C_{33})_{odd} \right) / \left( 2\sum(n\text{-}C_{24} - n\text{-}C_{32})_{even} \right)$$

CPI ranges from 4 to 17 (Table 8.1). One noticeable difference between the two deposits is the absence of very high values (i.e. CPI >12) at Bowmans.

Table 8.1 CPI summary by deposit

| | Lochiel Deposit | Bowmans Deposit |
|---|---|---|
| Minimum | 4.2 | 4.3 |
| Maximum | 16.9 | 11.9 |
| Average | **9.1** | **8.1** |
| Std Dev | 3.3 | 1.9 |
| Number of samples | 16 | 11 |

Similar *n*-alkane distributions have been reported in several low rank coals spanning the Eocene to Miocene and from various settings including the Gippsland Basin, the Baise Basin in southern China, Vermont USA, the Alpine Foreland Basin Austria and assorted German deposits (Chaffee and Johns, 1985; Hazai *et al.*, 1988; Li *et al.*, 1990; Wang and Simoneit, 1990; Del Rio *et al.*, 1992; Stout, 1992; Bechtel *el al.*, 2002; Bechtel *el al.*, 2003).

### 8.1.2 Sesquiterpenoids

Sesquiterpenoid abundance is low compared to that of the other terpenoid classes. Even so, 47 possible sesquiterpenoids were detected, mostly $C_{15}$ compounds. These belong to several sub-classes (viz. saturated, mono-unsaturated, di-unsaturated and partially aromatised), of which the mono-unsaturated ($M^+$ 206) sesquiterpenes are the most numerous and abundant (Figure 8.3; Appendix D1). Definitive structural assignment was possible for only a few compounds.

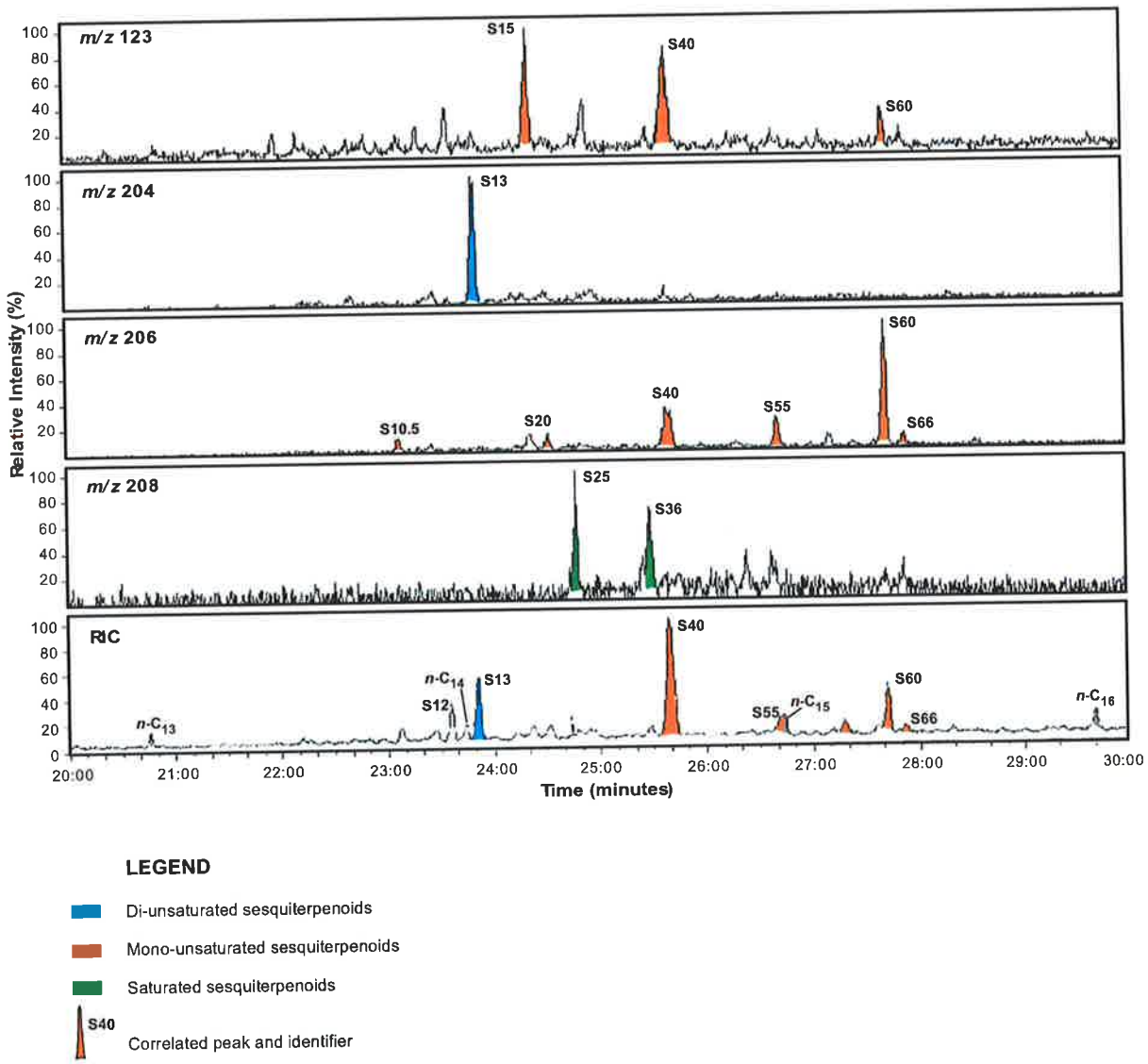



Figure 8.3 Representative sesquiterpenoid distribution

Saturated sesquiterpenoids ($M^+$ 208) are relatively minor components in terms of their relative abundance and distribution. Some fourteen $C_{15}$ compounds and single $C_{14}$ and $C_{16}$ members were detected (Figure 8.3; Appendix D1.1). The majority are rare to very rare and typically restricted to one or two samples. Compound identification is limited to one confident assignment (cadinane) and two tentative assignments (santalane and 8β(H)-drimane; Figure 2.6). The two most widely occurring members are cadinane and santalane.

Mono-unsaturated sesquiterpenoids ($M^+$ 206) are the most numerous and abundant of the sesquiterpenoids, constituting several of the more widespread and concentrated compounds (Figure 8.3). A suite of twenty possible members including sixteen $C_{15}$ compounds, two $C_{16}$ compounds and single $C_{14}$ and $C_{17}$ compounds were detected (Appendix D1.2). Over half the compounds are rare to very rare and occur in only one or two samples. Definitive identification was not achieved for any members, although some have mass spectra similar to those of unidentified compounds reported in Tertiary brown coals from the Baise Basin, south China (Wang and Simoneit, 1990).

Di-unsaturated sesquiterpenoids are typically present in low abundance and are rare to very rare. Ten possible members were tentatively identified including eight $C_{15}$ ($M^+$ 204) and two $C_{16}$ ($M^+$ 218) compounds (Appendix D1.3). Positive assignments were not achieved and reports of $M^+$ 204 sesquiterpenoids in brown coals are rare. Two members show a reasonable match with compounds reported in surface sediments and possibly represent cadinene-type sesquiterpenoids.

Three partially aromatised $M^+$ 202 compounds were detected, including cuparene, calamenene and 5,6,7,8, tetrahydrocadalene (Appendix D1.4). With the exception of calamenene these compounds are rare, although where present they exist in moderate to high abundance.

Several of the unidentified compounds show a characteristic $M^+$-43 fragment in their mass spectra, with $M^+$ -15 and $M^+$-29 ions also common, possibly suggesting a common cadalene skeleton (Moshonas and Lund, 1970; Hostettler *et al.*, 1989; Van Aarssen *et al.*, 1990a). Although sesquiterpenoids from brown coals are rarely evaluated in detail, the compound suite detected in the Lochiel and Bowmans coals appears to show some similarities to those identified in the Tertiary Baise Basin of south China and Miocene Styrian Basin of Austria (Wang and Simoneit, 1990; Bechtel *et al.*, 2002).

Based on their consistency and relative abundance, five major sesquiterpenoids were recognised with $M^+$ 206 compounds being dominant (Table 8.2; Appendix D2). A further eight are considered significant.

Table 8.2 Major sesquiterpenoids (in order of decreasing significance)

| Identi -fier | Compound Assignment | Compos -ition | Mol. Wt. | Base Peak | Type | Occurrence | Relative Abundance |
|---|---|---|---|---|---|---|---|
| S40 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 191 | Unsat. | very common | very high |
| S60 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 81/206 | Unsat. | very common | low - v. high |
| S20 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 191 | Unsat. | very common | mod - high |
| S35 | Santalane (?) | $C_{15}H_{28}$ | 208 | 123 | Sat. | very common | high |
| S13 | $C_{15}$ sesquiterpdiene | $C_{15}H_{24}$ | 204 | 161 | Di-uns. | very common | high |

Key: (?) tentative assignment

The most widely occurring and commonly most abundant sesquiterpenoid is an unassigned $C_{15}$ sesquiterpene (S40). As such it can occur at several times the concentration of the next most abundant member. Unlike many of the other compounds, it also occurs in coals where total sesquiterpenoid content is low and it is represented in all facies.

A further two unidentified $C_{15}$ sesquiterpenes (S60 and S20) are widespread throughout the sample suite. They occur in both deposits and while best developed in facies I, are often recognised in coals with low total sesquiterpenoid contents. While typically occurring in significant relative abundance (particularly S60), they do not constitute the dominant sesquiterpenoid in any sample.

The $C_{15}$ sesquiterpane tentatively identified as santalane occurs a somewhat erratically, but is common in most Bowmans coals where it occasionally represents the dominant sesquiterpenoid, while the unidentified $C_{15}$ sesquiterpdiene (S13) is common in both deposits. In addition to the major compounds, several others are occasionally significant, viz. S10, ($M^+$ 208), S39.8 ($M^+$ 204), S55 ($M^+$ 206) and S59 ($M^+$ 202).

With a few notable exceptions, the occurrence of sesquiterpenoids throughout the coal suite is highly erratic. One or two compounds may dominate their distribution in individual samples. Many are rare to very rare and several, including uncommon members, can constitute the most abundant sesquiterpenoid within individual samples.

Several sesquiterpenoids are detected in only one deposit, with the majority restricted to Bowmans coals (Appendix D1.1 to D1.4). Compounds specific to the Lochiel Deposit were recognised, but they are mainly limited to one sample showing an atypical sesquiterpenoid assemblage. Definitive assessment of deposit specificity is difficult because of the limited sample set and the generally erratic occurrence of these compounds. However, several of the Bowmans-specific compounds (most notably santalane) occur in multiple samples, supporting a genuine deposit preference.

In two facies I samples the sesquiterpenoid suite is highly atypical (L502 from sub-facies Ia at Lochiel, B28-57 from sub-facies Ib at Bowmans). The former contains several unique

compounds (i.e. restricted to the sample), while the major compounds normally present throughout the coal suite are absent. The latter displayed sesquiterpenoids in anomalously high concentration (i.e. approximately five times the facies average; Figure 8.4). Both features occur in coals typical of the facies. They are indicative of gross variations in compound occurrence and abundance, apparently independent of maceral assemblage (see Section 8.2.2).

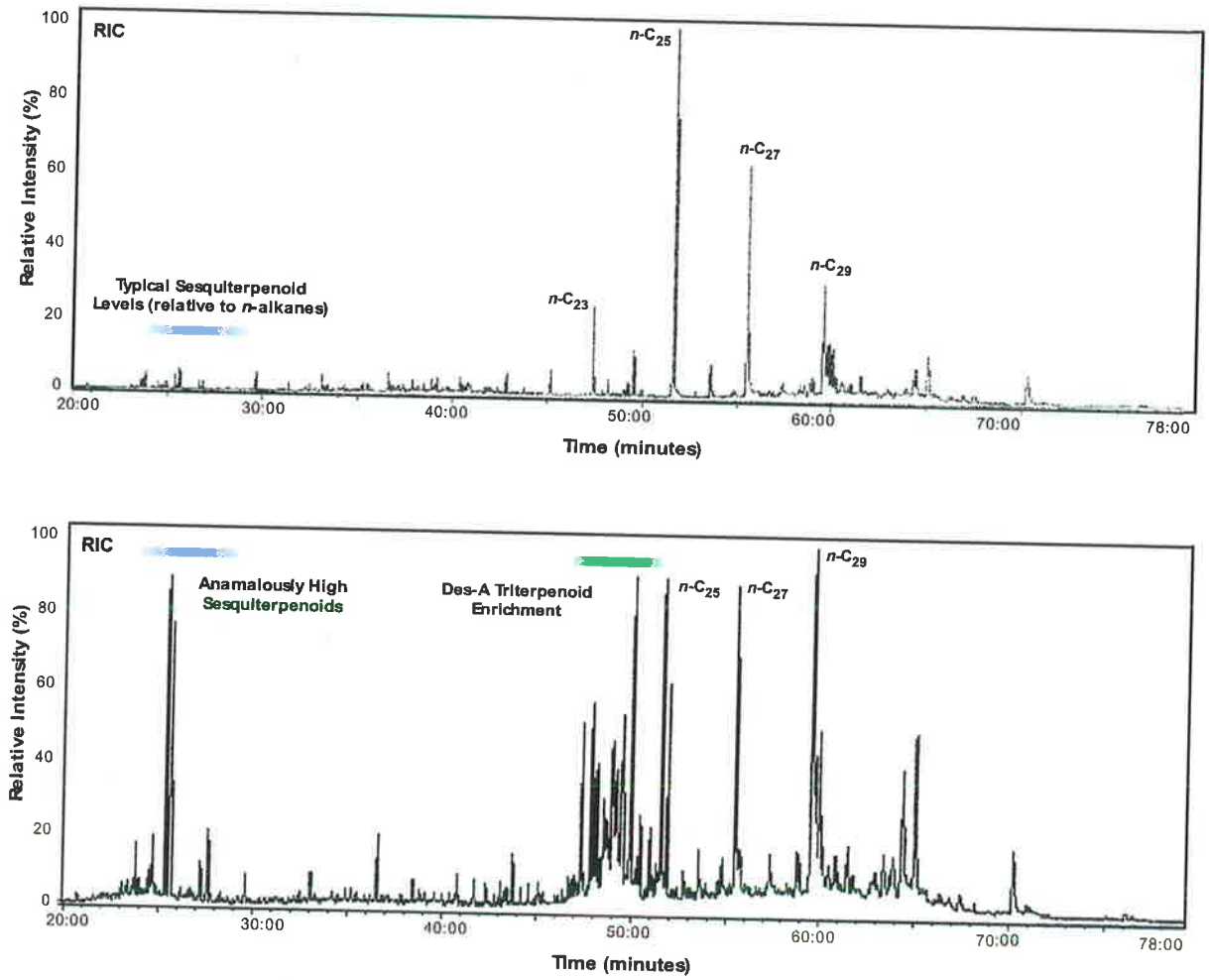



Figure 8.4 Anomalous sesquiterpenoid occurrence

### 8.1.3 Diterpenoids

An extensive suite of 64 possible diterpenoids was detected and correlated, including tri- and tetracyclic diterpanes and partially aromatised diterpenoids. In addition, several $M^+$ 274 and 272 compounds with dominant base peaks at *m/z* 259 and 257, respectively, were recognised (Figure 8.5). Definitive compound identification is largely restricted to members of the tricyclic and tetracyclic classes.

The diterpenoid suite is more extensive than typically reported for brown coals, in which assemblages dominated by tricyclics or a mixture of tricyclics and tetracyclics appear to be the norm. For example studies of assorted Eocene to Miocene age deposits, from widely

separated sites including the Gippsland Basin Australia, the Rhenish area and Helmstedt Deposit of Germany, northeast and south China, and the Styrian and Alpine Foreland Basins of Austria have noted such compound suites (Hagerman and Hollerbach, 1979; Chaffee, 1981; Livsey *et al.*, 1984; Winkler, 1986; Hazai *et al.*, 1988; Li *et al.*, 1990; Li and Johns, 1990; Wang and Simoneit, 1990; Ming *et al.*, 1994, Bechtel *et al.*, 2002; Bechtel *et al.*, 2003).

Saturated tricyclics constitute the dominant diterpenoid sub-group in terms of their number and relative abundance. Possible members include twelve $C_{20}$, five $C_{19}$ and one $C_{18}$ compounds, including isopimarane, pimarane, norditerpanes and isomers of abietane (Figures 2.6 and 8.5, Table 8.3; Appendix D1.5). Pimarane is the most widely occurring and abundant diterpenoid in the Lochiel and Bowmans coals.

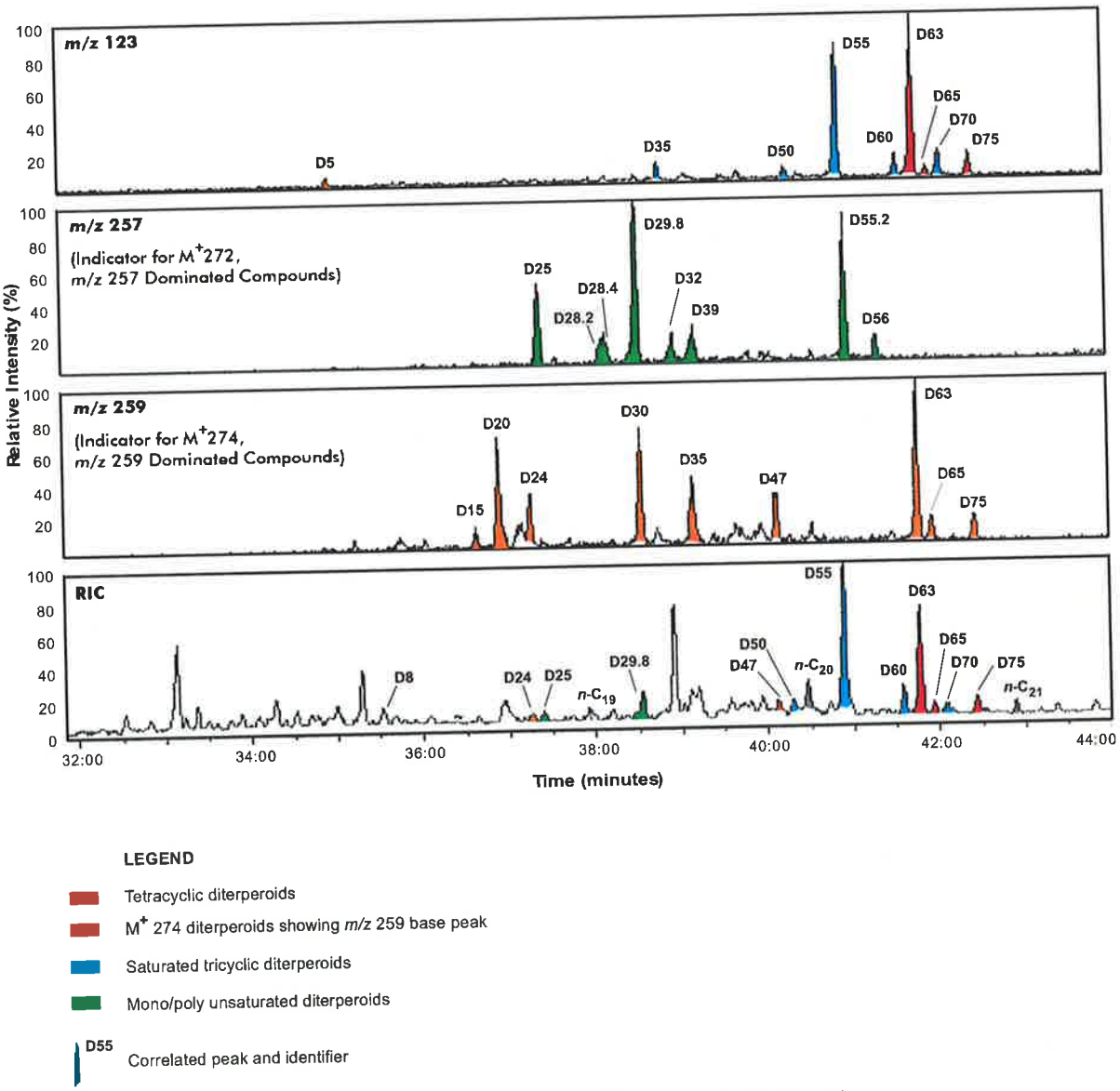



Figure 8.5 Representative diterpenoid distribution

The tetracyclic diterpenoids comprise one $C_{18}$ and five $C_{20}$ compounds (Figures 2.6 and 8.5; Appendix D1.6). They are widely distributed and members of this group constitute the dominant diterpenoid in some samples. Three compounds have been assigned structures (viz.

*ent*-beyerane, 16α(H)-phyllocladane and *ent*-16α(H)-kaurane), with the latter two being the most commonly encountered tetracyclics. A further member is tentatively identified as an isomer of *ent*–beyerane.

Thirteen $M^+$ 274 compounds with a dominant base peak of *m/z* 259 and primarily eluting prior to the tricyclic and tetracyclic diterpanes were detected and informally grouped (Figure 8.5; Appendix D1.7). Only one of these (D20) is a major component in terms of relative abundance and consistent of occurrence. Definitive identifications were not achieved, although several members closely resemble kaurane and $\Delta^{5,10}$-dihyrdrorimuene. Eight additional $M^+$ 274 compounds, characteristically dominated by a single fragment ion, such as *m/z* 241 and 132 were also informally grouped (Appendix D1.8). These compounds occur in low abundance and definitive compound assignment was not achieved.

Twelve unsaturated $C_{20}$ diterpenoids ($M^+$ 272, several dominated by a *m/z* 257 base peak) and an unsaturated $C_{19}$ compound were recognised and informally grouped (Figure 8.5; Appendix D1.9). Although common throughout the sample suite they typically occur in low abundance. Definitive identification was not achieved, although several members show similarities to known compounds such as sclarene, isopimaradiene and $\Delta^{5,10}$-rimuene. Possibly partially aromatised or poly-unsaturated diterpenoids include two $C_{20}$ ($M^+$ 270) and three $C_{19}$ ($M^+$ 256) compounds (Figure 8.5; Appendix D1.9). One member was identified as dehydroabietane and hence the remaining unassigned $M^+$ 270 compounds may also be partially aromatised compounds. The $M^+$ 256 compounds are similar to norabietatriene and 18-norabieta-8,11,13-triene, but were not positively identified.

Single $M^+$ 252 and $M^+$ 254 compounds were detected that are also possible diterpenoids (Appendix D1.10). Both may have abietane-type skeletons and are tentatively assigned as norabietatetraene and the di-aromatic compound simonellite, respectively.

Although compound abundance varies significantly between samples, eleven diterpenoids were identified as major compounds based on frequency of detection and relative abundance (Table 8.3; Figure 8.5; Appendix D2). Tricyclic and, to a lesser extent, tetracyclic compounds are dominant.

Table 8.3 Major diterpenoids (in order of decreasing significance)

| Identi-fier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Type | Occurrence | Relative Abundance |
|---|---|---|---|---|---|---|---|
| D55 | Pimarane (?) | $C_{20}H_{36}$ | 276 | 247 | Tri- | very common | very high |
| D63 | 16α(H)-phyllocladane | $C_{20}H_{34}$ | 274 | 123 | Tetra- | common | mod – v. high |
| D75 | *ent* -16α(H)-kaurane | $C_{20}H_{34}$ | 274 | 123 | Tetra- | common | high |
| D29.8 | Sclarene/iso-pimaradiene/abietadiene(?) | $C_{20}H_{32}$ | 272 | 257 | $M^+$272 [257] | very common | mod - high |
| D60 | Abietane | $C_{20}H_{36}$ | 276 | 163/ 276 | Tri- | uncommon | mod – high |
| D35 | Norpimarane | $C_{19}H_{34}$ | 262 | 233 | Tri- | common | mod – high |
| D64 | Abietane isomer | $C_{20}H_{36}$ | 276 | 163 | Tri- | common # | mod – v high |
| D20 | $\Delta^{5,10}$-dihydrorimuene or diasteriomer of kaurane | $C_{20}H_{34}$ | 274 | 259 | $M^+$274 [259] | very common | mod - high |
| D25 | Sclarene/iso-pimaradiene/abietadiene(?) | $C_{20}H_{32}$ | 272 | 257 | $M^+$272 [257] | very common | mod -high |
| D80 | $C_{20}$ tricyclic diterpane | $C_{20}H_{36}$ | 276 | 191 | Tri- | uncommon# | high – v. high |
| D15X | norditerp-triene | $C_{19}H_{28}$ | 256 | 241 | Arom | common | mod - high |

Key: (?) tentative assignment
# detected in the Bowmans Deposit only

The saturated tricyclic pimarane (D55) is the most widespread diterpenoid, occurring throughout the coal suite and typically represents the dominant member, especially within Lochiel coals. Other compounds commonly occurring in high relative abundance are the tetracyclics 16α(H)-phyllocladane and *ent*-16α(H)-kaurane (i.e. D63 and D75).

Abietane (D60) and the unknown $M^+$ 272 compound (D29.8) commonly occur at moderate to high relative levels, while the tricyclics norpimarane (D35) and a second abietane isomer (D64) are generally present in moderate (to occasionally significant) amounts. Of the two abietane isomers, D60 is largely restricted to Lochiel (most abundant in facies I), while D64 is limited to Bowmans coals where it sometimes represents the major diterpenoid. Norpimarane, although moderately variable, is widespread and occasionally abundant at Bowmans.

Other diterpenoids such as the unknown $M^+$ 274 and $M^+$ 272 compounds, (i.e. D20 and D25, respectively), an unassigned tetracyclic D80 and the $M^+$ 270 compound D15X can also be significant, but are less common. The former two compounds are very widespread and present in most coals from Lochiel and Bowmans, while the latter members are best developed at Bowmans, where in places they are the dominant diterpenoid.

Overall the occurrence and distribution of the diterpenoids at Lochiel and Bowmans is less variable than that of the sesquiterpenoids, as has been noted in other brown coals deposits (Hagemann and Hollerbach, 1980; Hazai *et al.*, 1988; Li *et al.*, 1990; Li and Johns, 1990; Killops *et al.*, 1995). Notwithstanding this finding, several diterpenoids show an erratic

occurrence and significant variations exist in both relative compound abundance and the compound suite between samples.

Many of the very rare diterpenoids were detected in a single atypical sample from Bowmans (B28-4). Belonging to sub-facies Ib, this sample is characterised by extreme diterpenoid enrichment (17 times higher than the Bowmans sub-facies Ib average; Figure 8.6) and a significantly expanded compound suite (including 11 biomarkers specific to this sample). This extreme enrichment in diterpenoids is paralleled to some extent by elevated sesquiterpenoid abundance.

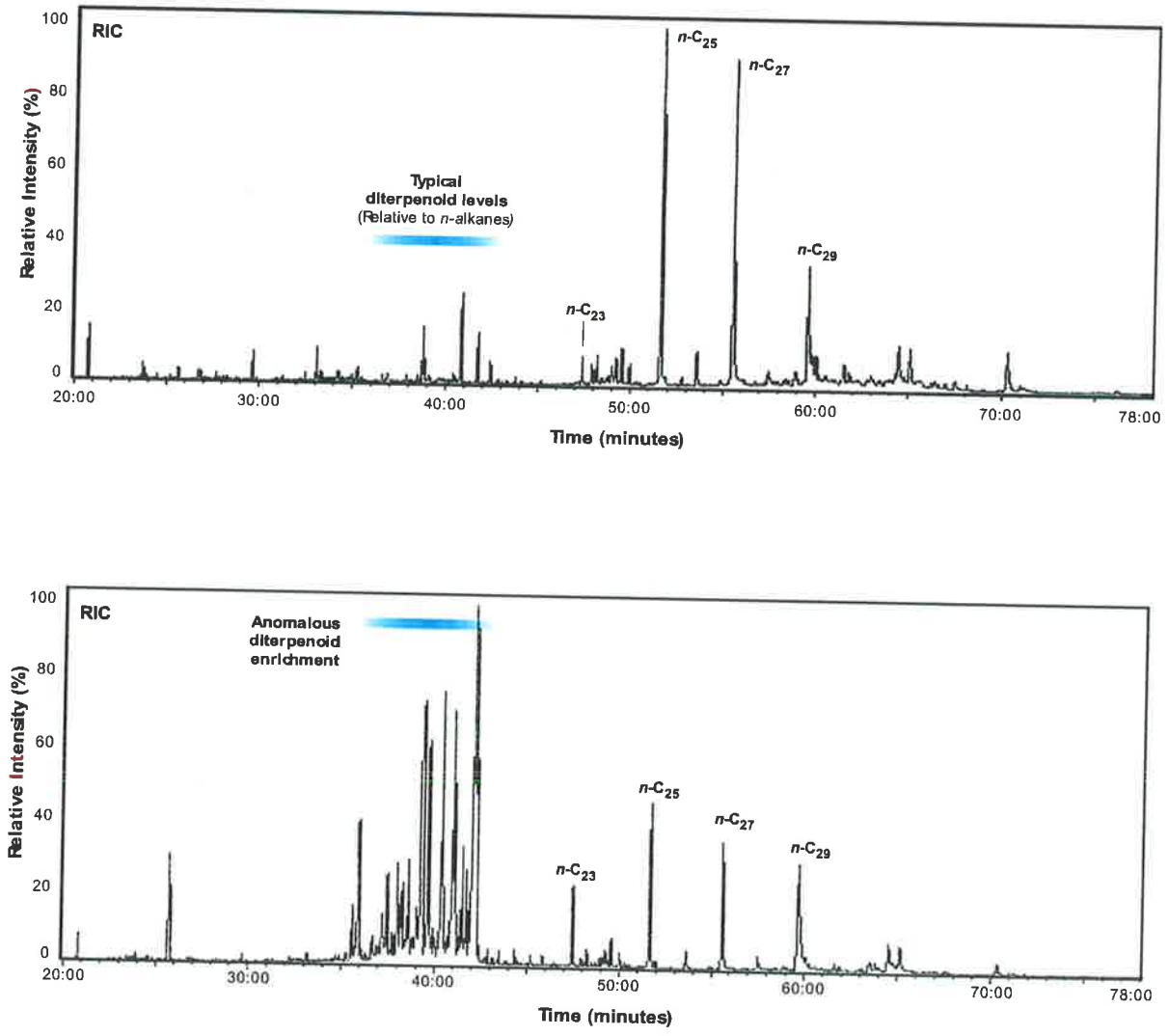



Figure 8.6 Anomalous diterpenoid occurrence

Of the total possible diterpenoid suite, 23 compounds are specific to the Bowmans deposit and three to Lochiel. Many of those from Bowmans occur in the anomalously diterpenoid-rich sample, suggesting that they may also be present elsewhere but at levels below the detection limit. However, other Bowmans-restricted compounds occur in multiple samples, indicating some deposit specificity. Alternatively, their detection may simply reflect the general enrichment of diterpenoids at Bowmans (see Section 8.2.3).

### 8.1.4 Intact terrigenous triterpenoids

Intact terrigenous triterpenoids recognised in the Lochiel and Bowmans coals include assorted non-hopanoid triterpenes. The term intact, or regular, is used herein to differentiate these compounds from other terrigenous triterpenoids in which the skeleton has been modified by diagenetic processes (see Sections 8.1.5 and 8.1.6).

Eight intact terrigenous triterpenes were detected including those with oleanene, fernene, ursene and possibly lupene skeletons. Of these, the oleanene compounds are the most abundant and numerous. Members are mostly mono-unsaturated, although some di-unsaturated compounds were also recognised.

The assignment of specific structures to these biomarkers is generally tentative, in line with their low abundance. However, six regular oleanenes, one fernene and one ursene were interpreted, although confident identification is limited to the most abundant member, olean-12-ene (Figure 2.6; Appendix D1.11). Two compounds, olean-2,12-diene and olean-13(18)-ene, have been tentatively identified. The remaining three oleanenes are provisionally assigned to be either oleana-2,18-diene or oleana-2,13(18)-diene, 18α-olean-12-ene and possibly 24-*nor* -olean-12-ene.

Intact terrigenous triterpenes are typically present in low concentration, with only olean-12-ene showing elevated levels (Figure 8.7). This compound is generally several times more abundant than other members of this group and represents a major triterpenoid. The dominance of olean-12-ene is consistent throughout the coal types in both deposits and is in line with previous research from assorted Eocene to Miocene deposits including the Gippsland Basin, the Helmstedt Deposit Germany, the Baise Basin south China and Vermont USA (Chaffee, 1981; Winkler, 1986; Wang and Simoneit, 1990; Stout, 1992). 18α-olean-12-ene can also exist in high concentration, but occurs less widely.

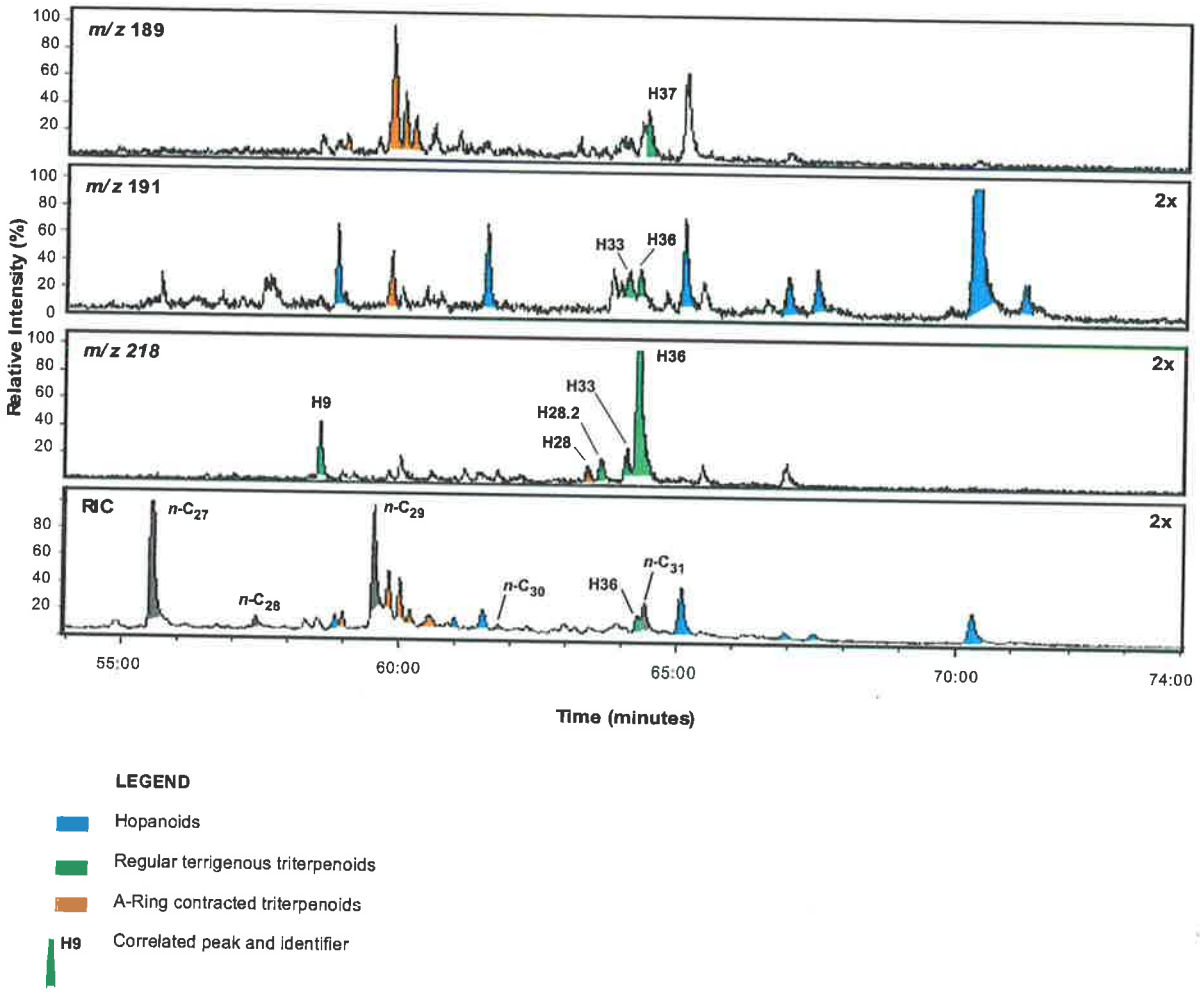



Figure 8.7 Representative intact terrigenous triterpenoid distribution

Intact terrigenous triterpenoids are distinguished by the consistency of their distribution and relative abundance across the sample suite in both deposits. With the exception of one very rare compound (H53), they are present in most samples.

### 8.1.5 A-ring-contracted triterpenoids

Twelve compounds interpreted as A-ring-contracted triterpenes occur in high abundance within the Lochiel and Bowmans coals and constitute the major non-hopanoid triterpenoids. These compounds show an intense $M^+$-43 ion and a key $M^+$-15 ion in their mass spectra, indicating loss of isopropyl and methyl groups, respectively, and elute mainly in the vicinity of the *n*-$C_{29}$ alkane. The rationale for A-ring-contracted triterpenoid assignment is discussed further in Appendix D1.12.

Three $C_{29}$ triterpdienes ($M^+$ 394) and seven $C_{30}$ triterpdienes ($M^+$ 408) were recognised. While homotriterpdienes are absent, two possible $C_{31}$ homotriterpenes ($M^+$ 424) with similar spectral characteristics were detected (Figure 8.8). Tentative compound assignment is limited

to one compound which shows similarities to A-*neo*-urs-3(5),12-diene and A-*neo*-olean-3(5),12-diene. Others are possibly derivatives of oleanene, ursene and lupene.

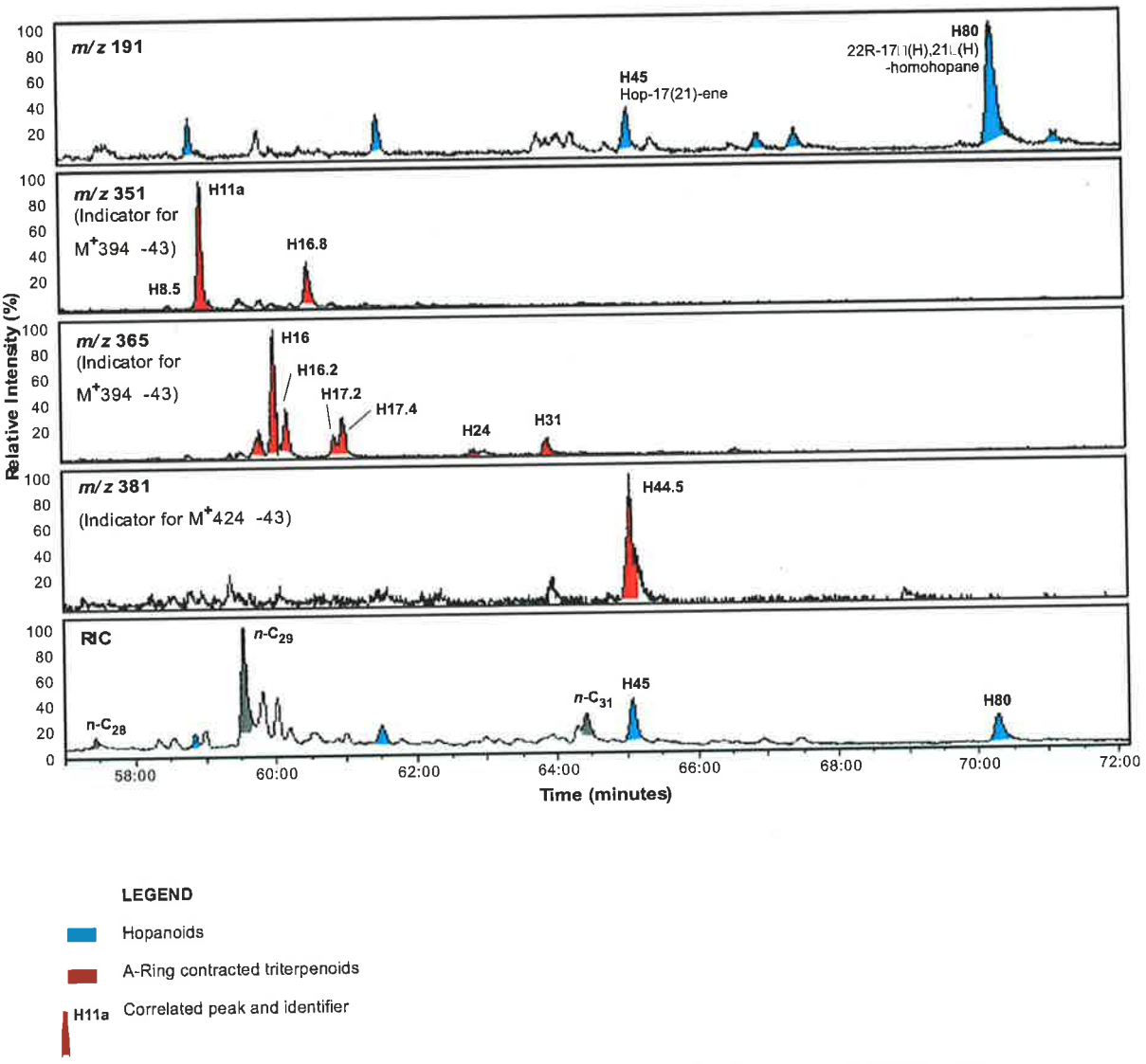



Figure 8.8 Representative A-ring contracted triterpenoid distribution

The dominant A-ring-contracted compounds include the unassigned $C_{30}$ triterpdienes H16 and H15, with the former being slightly more abundant (Table 8.4, Figure 8.8, Appendix D1.12). Other major compounds include H11a, H16.2, H16.8, H31 and H56, which are present at levels 30-40% that of H16.

Table 8.4 Major possible A-ring-contracted triterpenes (in approximate order of decreasing significance)

| Peak ID | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence | Relative Abundance |
|---|---|---|---|---|---|---|
| H16 | A-*neo*-oleana-3(5),12-diene or A-*neo*-urs-3(5),12-diene | $C_{30}H_{48}$ | 408 | 365 | very common | very high |
| H15 | A-*neo*-triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 190/408 | very common | very high |
| H11a | A-*neo*-nor-triterp-m,n-diene | $C_{29}H_{46}$ | 394 | 351 | very common | high |
| H16.2 | A-*neo*-triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 365 | very common | high |
| H16.8 | A-*neo*-nor-triterp-m,n-diene | $C_{29}H_{46}$ | 394 | 351 | common | high |
| H31 | A-*ne* -triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 365 | very common | high |
| H56 | A-*neo*-homo-triterp-m,n-ene | $C_{31}H_{52}$ | 424 | 381 | rare | moderate |

The occurrence and relative abundance of A-ring-contracted triterpenoids is very consistent throughout the coal suite and over both deposits. Their distribution is very regular with most members recognised in each sample. This pattern of consistency contrasts with the variability of the terrigenous biomarkers (notably the sesquiterpenoids and diterpenoids) but parallels the pattern shown by the intact terrigenous triterpenoids.

### 8.1.6 Des-A triterpenoids

A suite of 26 compounds elute between the $C_{23}$ and $C_{25}$ *n*-alkanes. They occur in significant abundance and are interpreted to be des-A-triterpenoids (Figure 8.9; Appendix D1.13). Most members are unsaturated, with dienes predominating. Some have des-A-oleanane and lupane skeletons and the remainder are also possibly derived from angiosperms.

Unsaturated $C_{22}$, $C_{23}$ and $C_{24}$ compounds interpreted as possible des-A triterpenoids include three des-A-triterptrienes, thirteen des-A-triterpdienes, and nine des-A-triterpenes. In addition one saturated $C_{24}$ compound was interpreted. Tentative identification is limited to 10α(H)-des-A-olean-13(18)-ene, des-A-lup-9-ene and des-A-lupane (Figure 2.6). A further three lupenes and an oleanane derivative are inferred, while several compounds show characteristics similar to unidentified des-A triterpenoids described elsewhere in brown coals (Chaffee, 1981; Trendel *et al.*, 1989; Wang and Simoneit, 1990; Stout, 1992; ten Haven *et al.*, 1992b; Logan and Eglinton, 1994). Significantly des-A-olean-12-ene was not detected, although unmodified olean-12-ene is abundant throughout the suite.

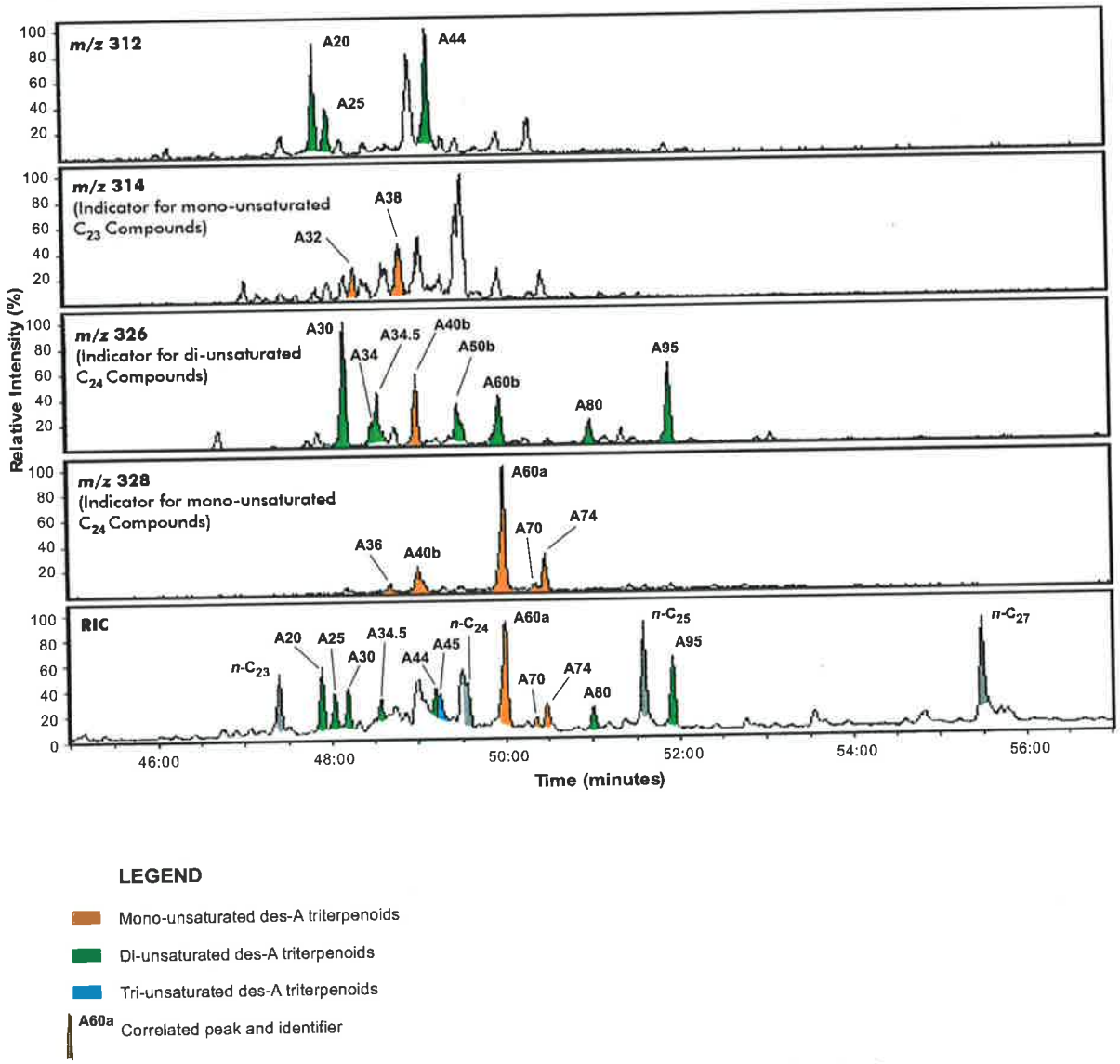



Figure 8.9 Representative des-A triterpenoid distribution

Although their relative abundance varies considerably between samples, eight members of the des-A triterpenoid suite were recognised as major compounds, with the majority being dienes (Table 8.5; Figure 8.9; Appendix D2).

Table 8.5 Major des-A-triterpenoids (in approximate order of decreasing significance)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence | Relative Abundance |
|---|---|---|---|---|---|---|
| A30 | "A" of Stout (1992) | $C_{24}H_{38}$ | 326 | 326 | very common | high |
| A20 | | $C_{23}H_{36}$ | 312 | 269 | very common | high |
| A40a | "C" of Stout (1992) | $C_{24}H_{38}$ | 326 | 326 | common | high |
| A45 | "D" of Stout (1992) | $C_{24}H_{36}$ | 324 | 324 | common | high |
| A25 | | $C_{23}H_{36}$ | 312 | 269 | common | high |
| A60a | des-A-lup-9-ene | $C_{24}H_{40}$ | 328 | 136 | uncommon | low – mod. |
| A50a | | $C_{23}H_{38}$ | 314 | 95/191 | rare # | high |
| A40b | 10αdes-A-olean-13(18)-ene (?) | $C_{24}H_{40}$ | 328 | 109/328 | uncommon | mod. - high |
| A95 | Possible lupene compounds / Possibly "K" of Stout (1992) | $C_{24}H_{38}$ | 326 | 136 | uncommon | high |

Key: # detected in the Bowmans Deposit only; (?) tentative assignment

The first five des-A triterpenoids (from Table 8.5) occur consistently throughout both deposits, generally in high relative abundance. The remaining major members are more restricted in occurrence and are typically best developed at Bowmans. In particular, A50a is only rarely recognised, but where present typically shows the highest relative abundance.

The occurrence of des-A triterpenoids tends be erratic, so that the precise composition and nature of the suite can vary significantly between samples and with coal type. Of the 26 possible des-A triterpenoids, ten are rare or very rare, being detected in just one or two samples. The dominant des-A triterpenoid is generally one of the major biomarkers listed in Table 8.5, although other members may also occur in elevated concentrations.

Des-A triterpenoids are much more common at Bowmans, where ten of them are deposit-specific biomarkers.

### 8.1.7 Hopanoids

Hopenes, hopanes and moretanes are ubiquitous throughout the Lochiel and Bowmans coals. Both the distribution and relative abundance of these bacterial biomarkers are broadly consistent across all facies and both deposits.

Sixteen hopanoids comprising $C_{27}$, $C_{29}$ and $C_{30}$ hopenes (n = 5), $C_{27}$ and $C_{29}$ - $C_{31}$ hopanes (n = 8) and $C_{29}$ - $C_{31}$ moretanes (n = 3) were detected (Figure 8.10; Appendix D1.14). Hopanoids differ from most of the other biomarker groups assessed in this study in that a high level of compound identification was achieved, reflecting their more extensive evaluation in the organic geochemical literature and relatively consistent compound occurrence.

The hopenes include some with rearranged structures. They are: 22,29,30-trisnorhop-13(18)-ene, 30-norneohop-13(18)-ene, 30-norhop-17(21)-ene, hop-17(21)-ene and neohop-13(18)-ene (Figure 2.6).

The hopanoids with a 17β or 17β,21β configuration are 17β(H)-22,29,30-trisnorhopane, 17β(H),21β(H)-30-norhopane, 17β(H),21β(H)-hopane and 17β(H),21β(H)-homohopane. Those with a 17α, 21β configuration include 17α(H),21β(H)-30-norhopane, 17α(H),21β(H)-hopane and 22S and 22R 17α(H),21β(H)-homohopane.

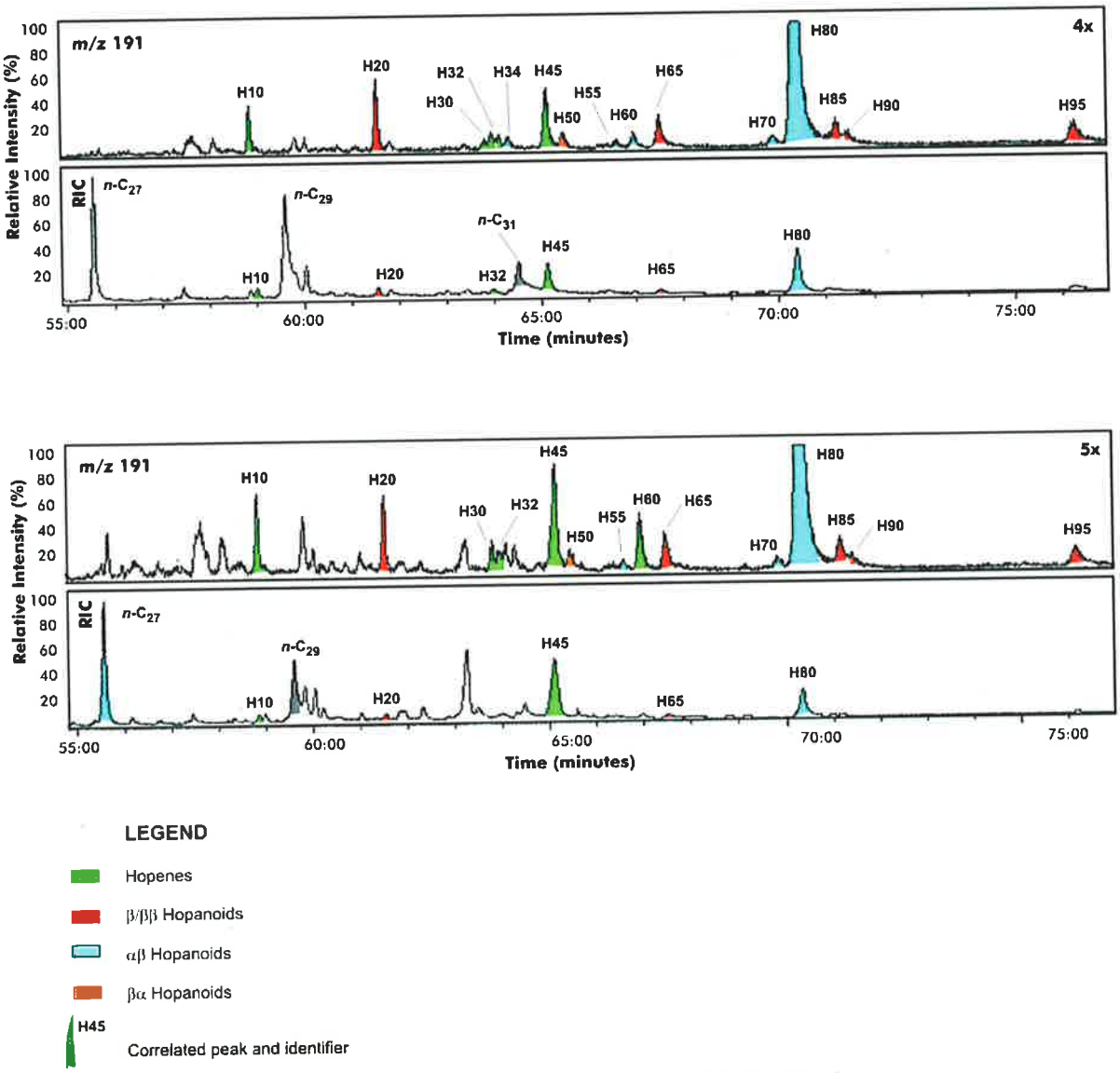



Figure 8.10 Representative hopanoid distribution

The βα– hopanoids identified include 17β(H),21α(H)-30-normoretane and 17β(H),21α(H)-homomoretane. A third compound present in very low abundance may possibly be 17β(H),21α(H)-moretane (Appendix D1.14). Moretanes typically occur in low concentration in the Lochiel and Bowmans coals.

Several $M^+$ 414 compounds with a dominant *m/z* 123 fragment ion elute between the des-A-triterpenoids and hopanoids (i.e. in the vicinity of the $C_{26}$ and $C_{27}$ *n*-alkanes). The mass spectra of these compounds have many similarities to those of the $C_{30}$ 8,14-secohopanes (Philp, 1985) and are tentatively assigned to this group of isomers. Approximately five such compounds appear to be moderately consistent in their occurrence across facies and deposits between samples. They occur in relatively minor abundance relative to the other hopanoids.

Six hopanoids qualify as major components in terms of their abundance and consistency of occurrence, with 22R-17α(H),21β(H)-homohopane and hop-17(21)-ene dominant (Table 8.6;

Figure 8.10; Appendix D2). In addition, 17β(H),21β(H)-homohopane and 30-norhop-17(21)-ene are generally present in moderate amounts.

Table 8.6 Major hopanoids (in order of decreasing significance)

| Ident-ifier | Compound Designation | Compos-ition | Mol. Wt. | Base Peak | Occurrence | Relative Abundance |
|---|---|---|---|---|---|---|
| H80 | 22R-17α(H),21β(H)-homohopane | $C_{31}H_{54}$ | 426 | 191 | very common | very high |
| H45 | hop-17(21)-ene | $C_{30}H_{50}$ | 410 | 367/231 | very common | high-very high |
| H10 | 22,29,30-trisnorhop-13(18)-ene | $C_{27}H_{44}$ | 368 | 176 | very common | moderate |
| H20 | 17β(H)-22,29,30-trisnorhopane | $C_{27}H_{46}$ | 370 | 149 | very common | moderate - high |
| H60 | neohop-13(18)-ene | $C_{30}H_{50}$ | 410 | 191 | very common | moderate |
| H65 | 17β(H),21β(H)-30-norhopane | $C_{29}H_{50}$ | 398 | 177 | very common | moderate |

A consistently high concentration of 22R-17α(H),21β(H)-homohopane is a feature of the Lochiel and Bowmans samples, as it is in other brown coals (Chaffee, 1981; Winkler, 1986; Hazai *et al.,* 1988; Li *et al.,* 1990; ten Haven *et al.*, 1992a; Stout, 1992; Lu and Kaplan, 1992; Ming *et al.*, 1994; Stefanova *et al.,* 1995). This biomarker exists in high abundance in all coal facies and throughout both deposits. At Lochiel it is the dominant hopanoid. Hop-17(21)-ene is commonly the most abundant hopanoid at Bowmans and is significant in all coal types from both deposits. It is also the most frequently identified hopene in brown coal (Winkler, 1986; Li *et al.,* 1990; Li and Johns, 1990; Wang and Simoneit, 1990; Stout, 1992; Bechtel *et al.*, 2002).

The suite of hopanoids identified in the coals at Lochiel and Bowmans is very consistent between samples and are either very similar, or identical, to those in other lignite deposits (Chaffee, 1981; Venkatesan *et al.*, 1986; Winkler, 1986; Hazai *et al.,* 1988; Li *et al.,* 1990; Li and Johns, 1990; Wang and Simoneit, 1990; ten Haven *et al.*, 1992a; Stout, 1992; Dehmer, 1993; Ming *et al.*, 1994). Relative compound abundance also appears broadly consistent across the sample suite. Slight departures in the regular nature of hopanoid occurrence were however detected including a difference in the relative abundance of the two major hopanoids between deposits (see Section 8.2.7). Furthermore, within a typical sub-facies IIa coal from Bowmans, the normally abundant 22R-17α(H),21β(H)-homohopane occurs in very low concentration, while other hopanoid members broadly parallel the pattern of occurrence within the remainder of the sample suite.

### 8.1.8 Steroids

Five backbone-rearranged sterenes and two sterenes were recognised in the Lochiel and Bowmans coals (Figure 8.11, Appendix D1.15). They include one $C_{27}$ diasterene ($M^+$ 370), four $C_{29}$ diasterenes and two $C_{29}$ sterenes ($M^+$ 398). The dominant diasterene was identified as 24-ethyl-diacholest-13(17)-ene and three other diasterenes are possibly isomers of this compound (Figure 2.6). The remaining diasterene has been tentatively identified as 20R-diacholestene. Of the sterenes, one resembles 24R-24-ethylcholest-4-ene.

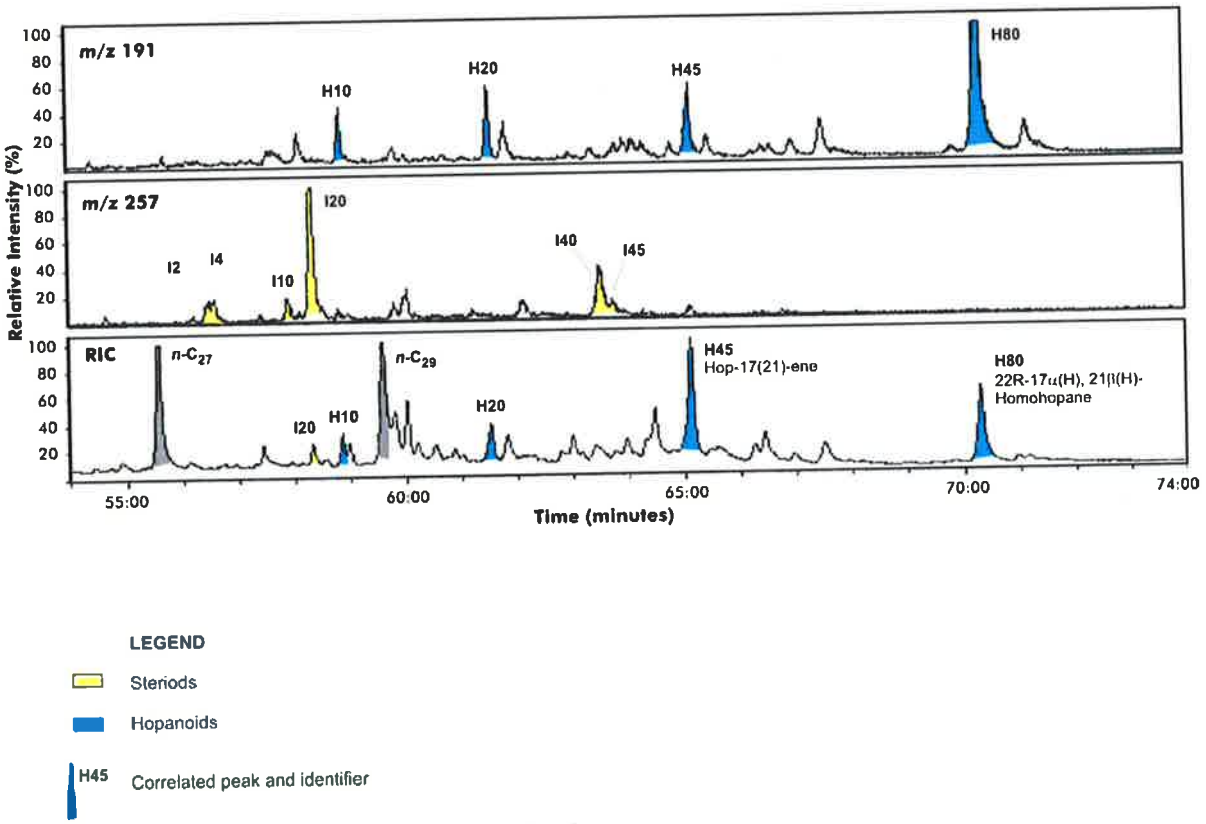



Figure 8.11 Representative steroid distribution

This restricted suite of steroids is relatively consistent and, while not necessarily present in all samples, appears to span the facies range and occur in both deposits. 24-ethyl-diacholest-13(17)-ene is several times more abundant than any other member and is also the most widespread (Appendix D2). The Lochiel and Bowmans steroids appear consistent with findings from other brown coal evaluations, particularly the predominance of $C_{29}$ homologues (Curiale and Lin, 1991; Lu and Kaplan, 1992; Stefanova *et al.*, 1995) and occurrence of diasterenes (Wang and Simoneit, 1990; Winkler, 1986).

## 8.2 DISTRIBUTION WITHIN FACIES AND DEPOSIT

The abundance of the various terpenoid classes with respect to primary facies (i.e. I, II and III) and deposit is considered in this section using various relative concentration index (RCI) parameters to facilitate cross sample comparison. Anomalous occurrences such as extreme abundances and atypical compound suites are also reviewed. The methodology for RCI estimation is outlined in Appendix D3.1.

The sample set used for biomarker evaluation comprises only 26 coals, (15 from Lochiel and 11 from Bowmans). Caution is therefore necessary in evaluating abundance variations, especially for sub-facies where in some cases only single samples were available. The biomarker sample set is outlined in Appendix D3.1.

### 8.2.1 Normal alkanes

No consistent correlation of *n*-alkane abundance with primary facies was established, although significant differences are evident between deposits and the partially combusted sub-facies IVa coal shows a major reduction in abundance (Table 8.7; Appendix D3.2). Thus, variations in the pattern of *n*-alkane occurrence, while apparent across the sample suite, cannot be unambiguously linked to changes in coal type at Lochiel and Bowmans.

Table 8.7 RCI of *n*-alkanes by facies and deposit

| Coal Type | Lochiel Deposit | | | Bowmans Deposit | | |
|---|---|---|---|---|---|---|
| | Sub-Facies | Facies | Deposit | Sub-Facies | Facies | Deposit |
| *Sub-facies Ic* | *65* | } | } | *6* | } | } |
| *Sub-facies Ib* | *21* | } 39 | } | *17* | } 16 | } |
| *Sub-facies Ia* | *48* | } | } 32 | *16* | } | } 17 |
| Facies II | | 32 | } | *10 / 25** | | } |
| Facies III | | 28 | } | | | |
| *Sub-facies IVa* | 3 | | | | | |

Key: *These values relate to the IIa-2 and IIa-3 sub-varieties

On average *n*-alkanes are significantly more abundant at Lochiel where RCI is subject to much greater fluctuation, especially in facies I. At Bowmans RCI is relatively consistent between facies. The poor correlation of *n*-alkane concentration with coal type suggests that it is unrelated to the abundance of liptinites such as cutinite, frequently suggested as a source of high-molecular-weight *n*-alkanes (Tissot and Welte, 1984; Philp, 1985; Hazai *et al.*, 1988; Wang and Simoneit, 1990; Peters and Moldowan, 1993). This departure is most pronounced in facies III where although cutinite is minor, *n*-alkane abundance is only slightly lower than levels in facies I and II (Table 8.7).

### 8.2.2 Sesquiterpenoids

Some correlation is apparent between coal type and total sesquiterpenoid abundance, the latter being highest in facies I, low to moderate in facies II and very low in facies III (Table 8.8; Appendix D3.3). The inertinite-rich sub-facies IVa coal has very low sesquiterpenoid levels. While there is no consistent pattern between sub-facies and deposits, it is the terrestrial coal types that contain the highest concentrations of sesquiterpenoids. These findings broadly concur with previous research that demonstrated sesquiterpenoid enrichment in woody liptinite-rich coals, and reduced levels in highly inertinitic coals (Hagemann and Hollerbach, 1980; Simoneit *et al.*, 1986; Ming *et al.*, 1994). Overall, sesquiterpenoid abundance appears slightly greater in the Bowmans Deposit.

Table 8.8 Average RCI of major sesquiterpenoids by facies and deposit

| Coal Type | Lochiel Deposit | | | Bowmans Deposit | | |
|---|---|---|---|---|---|---|
| | Sub-Facies | Facies | Deposit | Sub-Facies | Facies | Deposit |
| *Sub-facies Ic* | *36* | } | } | *244 ** | } | } |
| *Sub-facies Ib* | *28* | } 35 | } | *55* | } 48 # | } |
| *Sub-facies Ia* | *41* | } | } 15 | *8* | } | } 41 # |
| Facies II | | 8 | } | *6 / 35*** | | } |
| Facies III | | 1 | } | | | |
| ***Sub-facies IVa*** | *1* | | | | | |

Key: * Based on a single highly sesquiterpenoid rich sample
# Average excludes the highly sesquiterpenoid-rich sample.
**These values relate to the IIa-2 and IIa-3 sub-varieties

Interestingly, there is no major difference between sub-facies I varieties at Lochiel, despite their contrasting maceral assemblages. At Bowmans, however, sesquiterpenoid levels appear well differentiated according to coal type, such that RCI is highest in sub-facies Ic and decreases systematically through the Ib and Ia varieties.

Marked departures in sesquiterpenoid abundance and composition occur independently of maceral content and facies. The most pronounced involves extreme sesquiterpenoid enrichment in a Bowmans sub-facies Ic coal (L610), wherein levels are approximately five times the deposit and facies averages (Table 8.9). In addition, anomalously low sesquiterpenoid levels were noted in a sub-facies Ib coal from Lochiel, while in a further sample an atypical sesquiterpenoid suite was recognised. In all these instances the coals appeared petrographically representative of the facies. These features may relate to very local palaeobotanical factors and may also partly reflect the inherent variability of sesquiterpenoid occurrence in the Lochiel and Bowmans coals. Erratic sesquiterpenoid occurrence, varying independently of coal type, was reported by Ming *et al.* (1994) in their study of pale and dark brown coal from the Yunan Province, China.

Comparison of the average RCI values for the sesquiterpenoid sub-groups shows a broadly similar distribution to that of major sesquiterpenoids. However, marked departures occur in

the anomalously sesquiterpenoid Bowmans coal (L610) where sesquiterpanes are the dominant species (Table 8.9).

Table 8.9 Comparison of average RCI values for sesquiterpenoid sub-groups in facies I coals at Bowmans with those of an anomalously rich sample

| Sample | Saturated | Sesquiterpenoid Sub-Group Mono-unsaturated | Di-unsaturated | Partly Aromatised | Total Sesquiterpenoid |
|---|---|---|---|---|---|
| Bowmans facies I average | 49 | 80 | 31 | 110 | 127 |
| Sample L610 (sub-facies Ic) | 490 | 91 | 76 | 352 | 639 |
| *Multiple* | ***10*** | *1.1* | *2.3* | *3.2* | *5* |

Key: * Average excludes the anomalously high value from sample L610

A Bowmans sub-facies Ia coal (B28-6) rich in large resinite phytoclasts (possibly bleed resins) facilitated further evaluation of the sesquiterpenoid composition and its relationship to this key liptinite maceral. While significantly enriched in resinite (~20% c.f. typically <5%) its total sesquiterpenoid content is close to the facies average and their diversity is low. The latter comprise an atypical suite of three main biomarkers (including a saturated $C_{14}$ and two $C_{15}$ mono-unsaturated compounds; S10, S40 and S40.5; Appendices D1.1 and D1.2), of which S10 and S40.5 are present in anomalously high concentration. Furthermore, santalane was absent despite occurring in almost all the other Bowmans samples analysed. However, notwithstanding the lack of correlation in this instance, a broad relationship between total sesquiterpenoid concentration and resinite content is apparent for the coal suite as a whole (Figure 8.12). A similar relationship was identified by Simoneit *et al.* (1986) in Eocene and Miocene brown coals from Germany and Fiji, respectively.

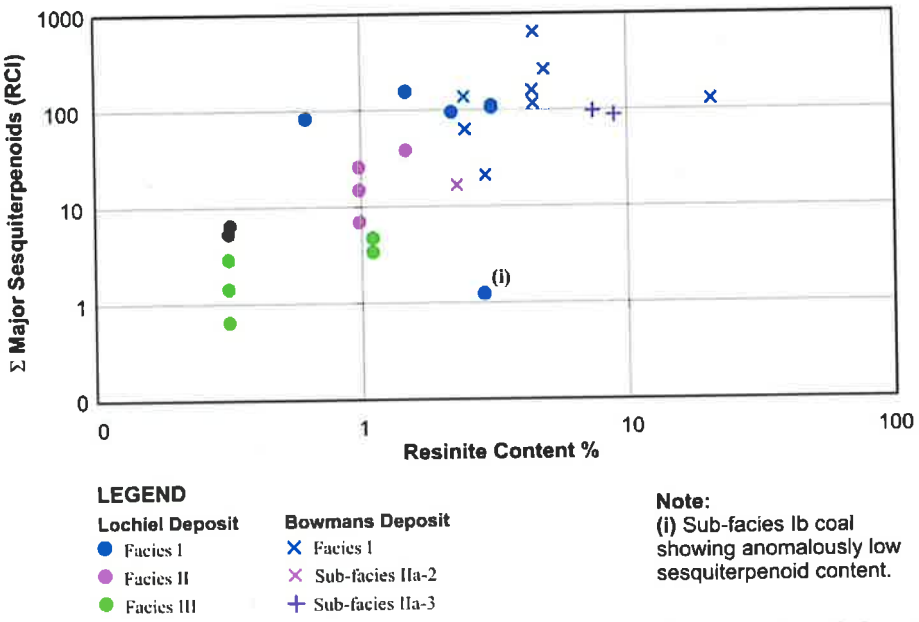



Figure 8.12 Relationship between sesquiterpenoid abundance and resinite content

### 8.2.3 Diterpenoids

Diterpenoid biomarkers display significant facies-related variation in abundance (Table 8.10, Appendix D3.4), especially at Lochiel where the highest concentrations (in terrestrial sub-facies Ia) differ from the lowest (in aquatic facies III) by a factor of approximately 50. A similar pattern of diterpenoid enrichment in humic coals and much lower levels in sapropelic coals was noted by Hagemann and Hollerbach (1980) and Bechtel *et al.* (2004).

Table 8.10 Average RCI for major diterpenoids by facies and deposit

| Coal Type | Lochiel Deposit Sub-Facies | Lochiel Deposit Facies | Lochiel Deposit Deposit | Bowmans Deposit Sub-Facies | Bowmans Deposit Facies | Bowmans Deposit Deposit |
|---|---|---|---|---|---|---|
| *Sub-facies Ic* | *5* | } | } | *7* | } | } |
| *Sub-facies Ib* | *4* | } 27 | } | *49 #* | } 38 # | } |
| *Sub-facies Ia* | *58* | } | } 13 | *15* | } | } 35 # |
| Facies II | | 3 | } | *5 / 40** | | } |
| Facies III | | 1 | } | | | |
| *Sub-facies IVa* | *1* | | | | | |

Key: # Excludes a sample which is approximately 50 times richer in diterpenoids than the other samples
*These values relate to the IIa-2 and IIa-3 sub-varieties

Over facies I coals the distribution with sub varieties differs considerably between deposits. The wood rich sub-facies Ia is enriched at Lochiel, while at Bowmans the concentrations are greatest in sub-facies Ib (Table 8.10).

In general, the diterpenoid sub-groups mirror the trends in abundance shown by the major diterpenoids with respect to facies and deposit. However, tetracyclics are notable for their

variable occurrence. They can be absent where other groups are common or, alternatively they may be abundant in coals that are otherwise diterpenoid poor. Furthermore, they are enriched within sub-facies Ia coal where they appear to be associated with highly gelified, possibly subaerial woody tissue. Tetracyclics also vary considerably between deposits and are approximately twice as common at Lochiel, while tricyclics are most abundant at Bowmans.

A broad correlation exists between diterpenoid abundance and resinite content (Figure 8.13a), although this relationship is less strong in the facies I sub-varieties at Lochiel. In particular, reduced diterpenoid levels are evident in sub-facies Ib and Ic (both resinite-rich), whereas higher diterpenoid concentrations are found in sub-facies Ia (with lower resinite contents). This finding parallels that of other studies highlighting inconsistencies between resinite abundance in the coal and diterpenoid content (Chaffee, 1981; Sheng *et al.,* 1992; Ming *et al.*, 1994). The massive telovitrinite index (MTI), a measure of wood content, shows a poor correlation with diterpenoid abundance (Figure 8.13b).

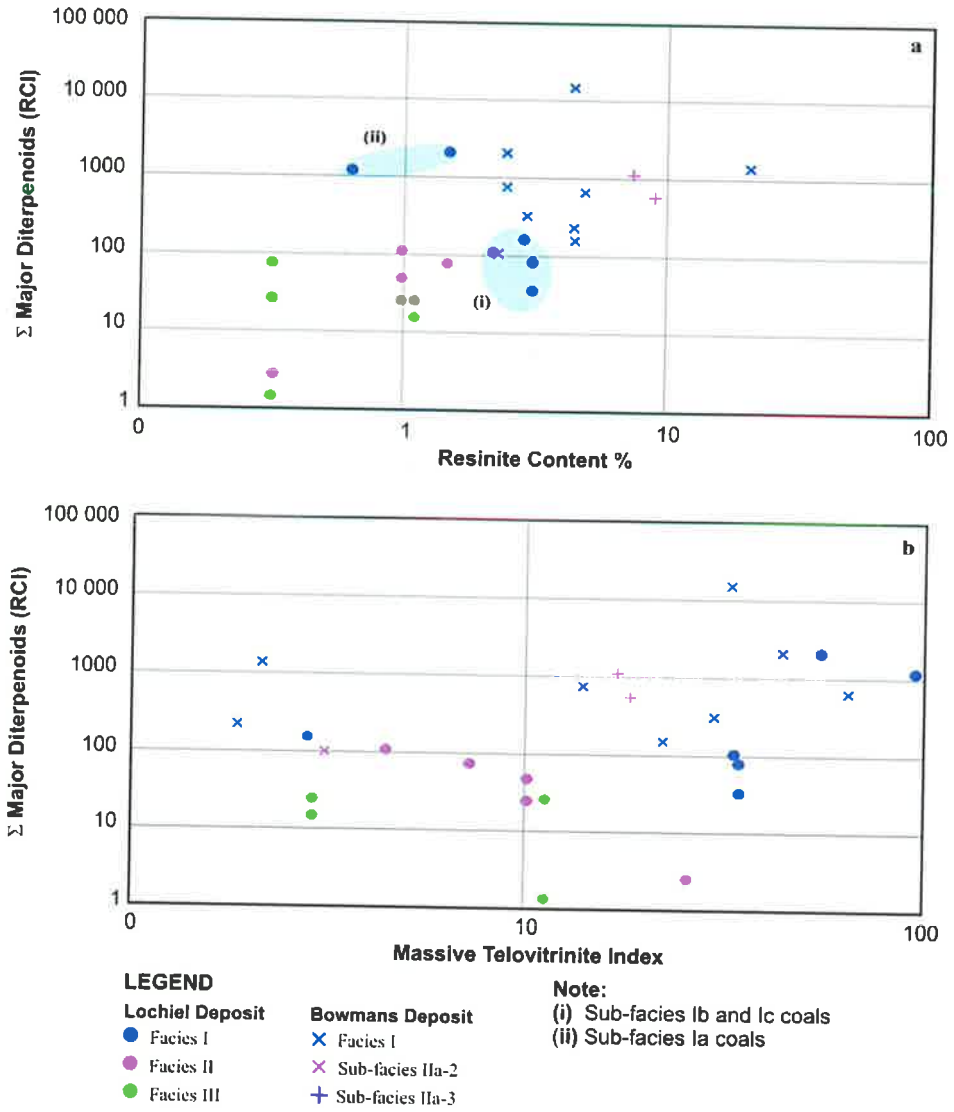



Figure 8.13 Relationship between diterpenoid abundance, resinite and telovitrinite

Highly anomalous diterpenoid levels (17 times the sub-facies average) were detected in a terrestrial sub-facies Ib coal from Bowmans (Table 8.11). Here the tetracyclic diterpanes are over 200 times more abundant than the facies average. Their anomalous occurrence cannot be linked to a marked change in maceral assemblage. Instead a mechanism independent of both facies (reflecting coal composition) and deposit (reflecting regional factors) is required. A very local change in source material, possibly related to a specific gymnosperm input, is tentatively postulated to explain this phenomena.

Table 8.11 Comparison of average RCI values for selected diterpenoid sub-groups in sub-facies Ib coals with that of an anomalously rich sample

| Sample | Diterpenoid Sub-Group # | | | | |
|---|---|---|---|---|---|
| | Tetracyclic diterpanes | $M^+274$ (259) | Other $M^+274$ | Tricyclic diterpanes | Total Diterpenoid |
| Sub-facies Ib average* | 6 | 52 | 32 | 73 | 42 |
| Sample B28 – 4 (sub-facies Ib) | 1274 | 395 | 126 | 902 | 704 |
| *Multiple* | ***212*** | *7.5* | *4* | *12* | *17* |

Key: * Average excludes the anomalously high value from the sample B28-4
# See Appendix D1 for explanation of diterpenoid categories

### 8.2.4 Regular terrigenous triterpenoids

Regular terrigenous triterpenoid levels (controlled primarily by olean-12-ene concentration) are much higher in facies I than in facies II and III, although the difference is more subtle at Bowmans (Table 8.12, Appendix D3.5). Elevated abundances of angiosperm biomarkers in woody and liptinite-rich humic coal (i.e. facies I) are consistent with the findings of previous studies of other brown coal deposits (Hagerman and Hollerbach, 1979; Chaffee, 1981; Winkler, 1986), while Chaffee (1981) also noted the absence of oleanenes in dark lithotypes of the Gippsland Basin (i.e. facies II/III equivalents).

Table 8.12 Average RCI for regular terrigenous triterpenoids by facies and deposit

| Coal Type | Lochiel Deposit | | | Bowmans Deposit | | |
|---|---|---|---|---|---|---|
| | Sub-Facies | Facies | Deposit | Sub-Facies | Facies | Deposit |
| *Sub-facies Ic* | *23* | } | } | *14* | } | } |
| *Sub-facies Ib* | *19* | } 29 | } | *35* | } 30 | } |
| *Sub-facies Ia* | *40* | } | } 16 | *21* | } | } 30 |
| Facies II | | 7 | } | *14 / 35** | | } |
| Facies III | | 9 | } | | | |

Key: *These values relate to the IIa-2 and IIa-3 sub-varieties

The facies I sub-types show only limited variation in the abundance of these biomarkers, suggesting that their concentration is unrelated to the major changes in the proportions of

telovitrinite and liptinite that occur across the facies. The angiosperm source affinity, rather than the specific maceral mix therefore appears to be a key factor in influencing their total abundance. Of the non-oleanenes, ursene is erratic although most concentrated in facies I.

None of the coals analysed displayed anomalous enrichment in the regular terrigenous triterpenoids, in marked contrast to the gymnosperm-derived diterpenoids. Abundance levels are similar between comparable coals of the Lochiel and Bowmans Deposits (i.e. facies I), although more variable in the latter.

### 8.2.5 A-ring-contracted triterpenoids

A-ring-contracted triterpenoids occur in considerable concentration, relative to other aliphatic biomarkers in the Lochiel and Bowmans coals (see Section 8.4.1). Their distribution with facies (Table 8.13, Appendix D3.6) is similar that exhibited by the regular terrigenous triterpenoids, with only moderate differences between sub-facies in facies I (again in stark contrast to the gymnosperm-derived biomarkers). Except in facies II, there is little difference between the Lochiel and Bowmans Deposits.

Table 8.13 Average RCI for A-ring contracted triterpenoids by facies and deposit

| Coal Type | Lochiel Deposit | | | Bowmans Deposit | | |
|---|---|---|---|---|---|---|
| | Sub-Facies | Facies | Deposit | Sub-Facies | Facies | Deposit |
| *Sub-facies Ic* | *44* | } | } | *28* | } | } |
| *Sub-facies Ib* | *23* | } 36 | } | *39* | } 40 | } |
| *Sub-facies Ia* | *47* | } | } 19 | *58* | } | } 37 |
| Facies II | | 9 | } | *32 / 30** | | } |
| Facies III | | 8 | } | | | |

Key: *These values relate to the IIa-2 and IIa-3 sub-varieties

Significantly reduced levels of A-ring-contracted triterpenoids are evident in a sub-facies Ib coal from Lochiel (V714-51) and are paralleled by slightly reduced regular terrigenous triterpenoids.

### 8.2.6 Des-A triterpenoids

Des-A triterpenoids show strong facies differentiation at Lochiel and a major variation in concentration between deposits (Table 8.14, Appendix D3.7). At Lochiel their abundance is greatest in facies I and, in relative terms, very low in facies II and III coals. At Bowmans these biomarkers are more than twice as abundant in facies I and concentrations much more consistent between samples in each of the sub-facies. The highest abundance occurs in a liptinite-rich sub-facies Ic coal from Bowmans and supports the association reported by

Chaffee (1981) between des-A triterpenoids and high liptinite lithotypes in the Gippsland Basin.

Table 8.14 Average RCI for des-A triterpenoids by facies and deposit

| Coal Type | Lochiel Deposit Sub-Facies | Facies | Deposit | Bowmans Deposit Sub-Facies | Facies | Deposit |
|---|---|---|---|---|---|---|
| *Sub-facies Ic* | *15* | } | } | *81* | } | } |
| *Sub-facies Ib* | *2* | } 21 | } | *39* | } 45 | } |
| *Sub-facies Ia* | ***54*** | } | } 8 | *n/a* | } | } 41 |
| Facies II | | 1 | } | *10 / 41** | | } |
| Facies III | | 1 | } | | | |

Key: *These values relate to the IIa-2 and IIa-3 sub-varieties

In summary, the distribution of des-A triterpenoids across the facies and between deposits broadly parallels those of the other angiosperm-derived triterpenoid biomarkers. However, a significant interdeposit difference in levels is apparent, whereby facies I concentrations in Bowmans coals are more that double those from Lochiel.

### 8.2.7 Hopanoids

The hopanoids in the Lochiel and Bowmans coals are dominated by 22R-17α(H),21β(H)-homohopane and hop-17(21)-ene which, although providing limited facies differentiation, vary significantly between deposits (Table 8.15; Appendix D3.8). The former tends to predominate in the Lochiel Deposit while the latter is more common at Bowmans.

Table 8.15 Average RCI of major hopanoids by facies and deposit

| Compound / Coal Type | Lochiel Deposit Sub-Facies | Facies | Deposit | Bowmans Deposit Sub-Facies | Facies | Deposit |
|---|---|---|---|---|---|---|
| **22R-17α(H),21β(H)-homohopane** | | | | | | |
| *Sub-facies Ic* | *51* | } | } | *4* | } | } |
| *Sub-facies Ib* | *24* | } 40 | } | *10* | } 10 | } |
| *Sub-facies Ia* | ***53*** | } | } 41 | *12* | } | } 13 |
| Facies II | | 42 | } | *0 / 27** | | } |
| Facies III | | 42 | } | | | |
| **Hop-17(21)-ene** | | | | | | |
| *Sub-facies Ic* | *24* | } | } | *15* | } | } |
| *Sub-facies Ib* | *14* | } 29 | } | *22* | } 20 | } |
| *Sub-facies Ia* | ***45*** | } | } 27 | *16* | } | } 21 |
| Facies II | | 13 | } | *15 / 25** | | } |
| Facies III | | 38 | } | | | |

Key: *These values relate to the IIa-2 and IIa-3 sub-varieties

The abundance of 22R-17α(H),21β(H)-homohopane appears to be largely unrelated to coal type, or at best varies only slightly with facies. However, a fourfold increase in the 22R-

17α(H),21β(H)-homohopane content of facies I coals at Lochiel, relative to those at Bowmans, represents a significant inter-deposit differential. The absence of this bacterial biomarker in one of the Bowmans sub-facies IIa coals represents a sample-specific feature, unrelated to maceral composition.

Hop-17(21)-ene has a similar distribution to that of 22R-17α(H),21β(H)-homohopane in the Lochiel coals where it displays significant intra-facies variability and provides limited facies differentiation. Its higher levels in facies III parallel increased biochemical gelification. In addition, hop-17(21)-ene is severely depleted in the weathered sub-facies IVb coal. Its abundance is broadly similar across both deposits, although slightly higher at Lochiel. The anomalously low concentration of 22R-17α(H),21β(H)-homohopane in a sub-facies IIa coal from Bowmans is not replicated by hop-17(21)-ene (Table 8.15).

22R-17α(H),21β(H)-homohopane is clearly more abundant than hop-17(21)ene , except in the facies I coals of the Bowmans Deposit (Table 8.16; Figure 8.14).

Table 8.16 Variation of 22R-17α(H),21β(H)-homohopane hop-17(21)-ene ratio with facies and deposit

| | Lochiel Deposit | | | Bowmans Deposit | |
|---|---|---|---|---|---|
| | **Facies I** | **Facies II** | **Facies III** | **Facies I** | **Facies II** |
| 22R-17α(H),21β(H)-homohopane / hop-17(21)-ene | 4.6 | 5.2 | 2.4 | 0.7 | 2.3 |

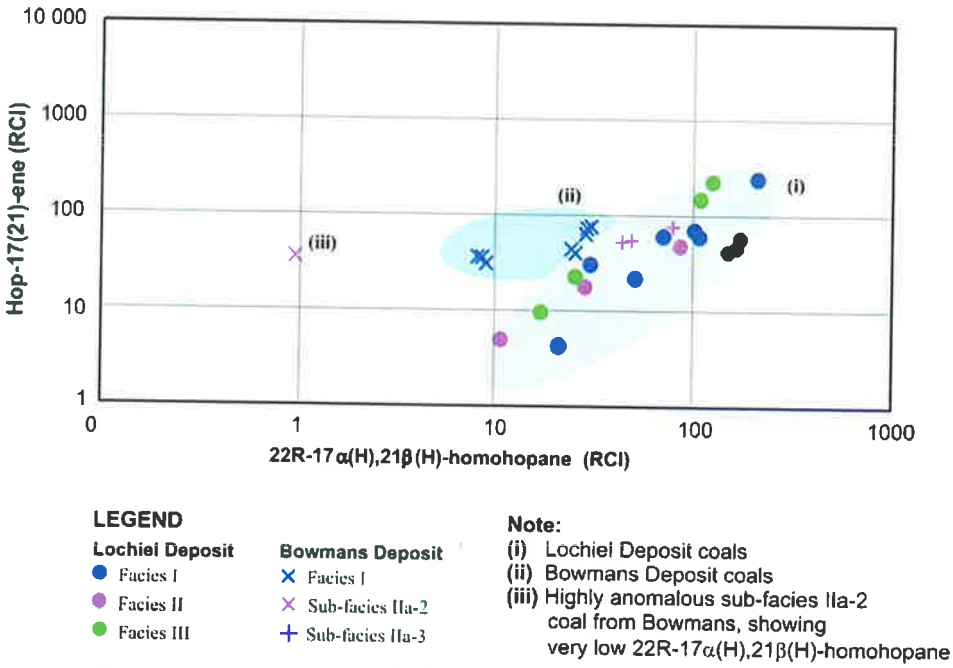



Figure 8.14 Relationship between the two major hopanoids

### 8.2.8 Steroids

Steroid abundance cannot be unambiguously related to facies. Significant sample to sample variation occurs, especially in facies II and III coals from Lochiel. In facies I sterene concentrations are broadly similar in both deposits. Anomalously high steroid levels were detected in a typical facies II coal from Lochiel and appear independent of maceral composition, paralleling similar phenomena in other biomarker groups.

### 8.2.9 Summary of biomarker distributions

In terms of their gross biomarker assemblages, the coals of the northern St. Vincent Basin appear broadly similar to those of brown coals elsewhere. This is particularly true of the hopanoids, although the sesquiterpenoids, diterpenoids and the des-A terrigenous triterpenoids appear more diverse and the A-ring-contracted triterpenes significantly more abundant.

#### 8.2.9.1 Biomarker characteristics of facies

The relative abundance of selected classes of gymnosperm and angiosperm biomarkers in this suite of 26 coals from the northern St. Vincent Basin is illustrated in Figures 8.15 and 8.16. Almost without exception, the highest levels of conifer-sourced sesquiterpenoids and diterpenoids and the angiosperm-derived triterpenoids occur in facies I. By comparison, their levels in facies II and III are significantly reduced to negligible. In contrast, the two major hopanoids and the waxy *n*-alkanes are poor discriminators of facies (Figures 8.16 and 8.17).

#### 8.2.9.2 Anomalous biomarker occurrences

Anomalous enrichment or impoverishment of biomarkers and development of atypical compound suites can occur without any apparent change in maceral composition (i.e. coals appear typical of the facies). The most notable instances are the extremely high concentrations of sesquiterpanes and tetracyclic diterpenoids and very low levels of the normally abundant 22R-17α(H),21β(H)-homohopane. Within such samples other biomarker concentrations are normally typical of facies and deposit, suggesting that these fluctuations are facies independent (as observed by Ming *et al.*, 1994) and possibly reflect the influence of very specific local palaeobotanical inputs, or alternatively involve unusual biogeochemical conditions.

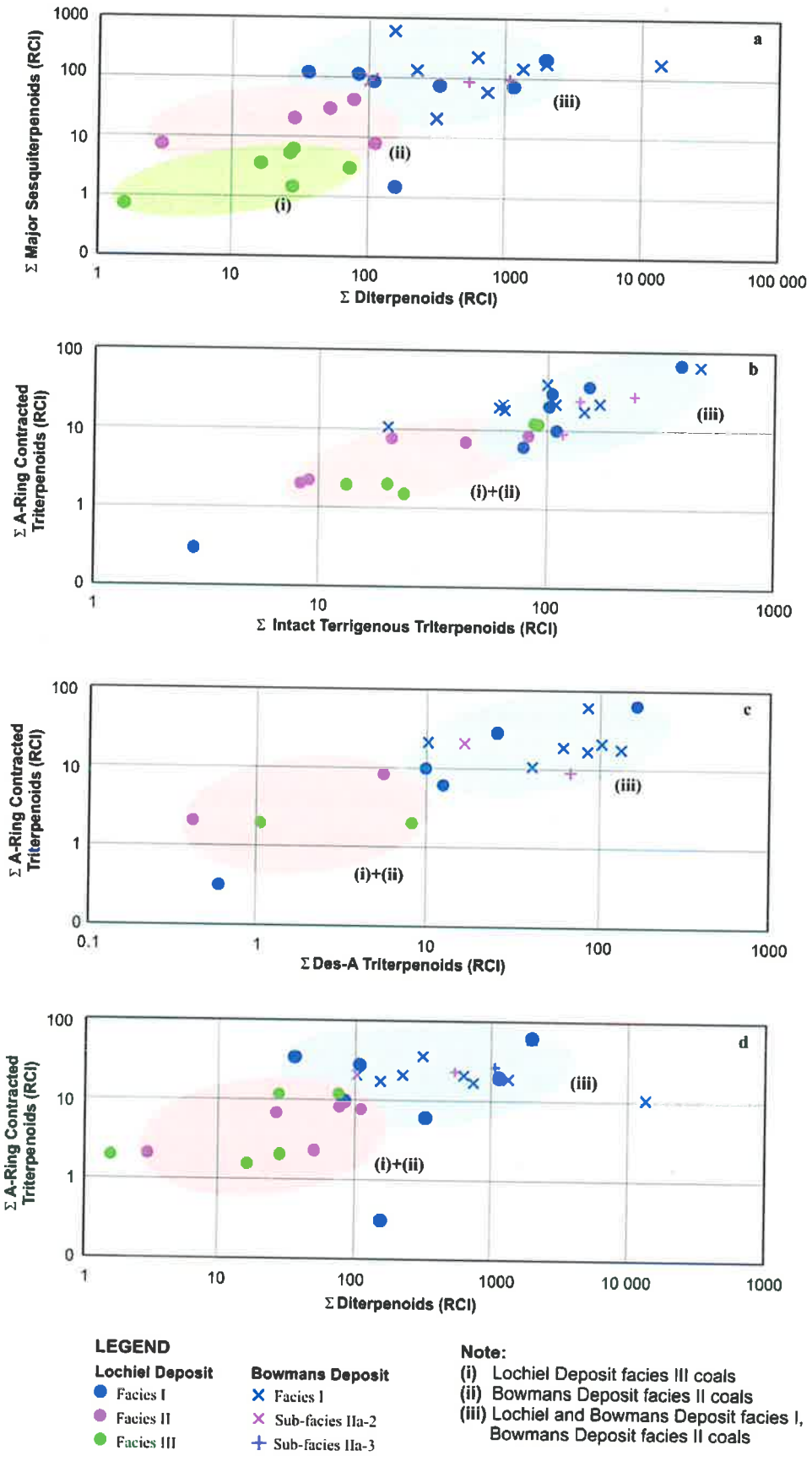



Figure 8.15 Relationships with and between gymnosperm and angiosperm biomarker groups

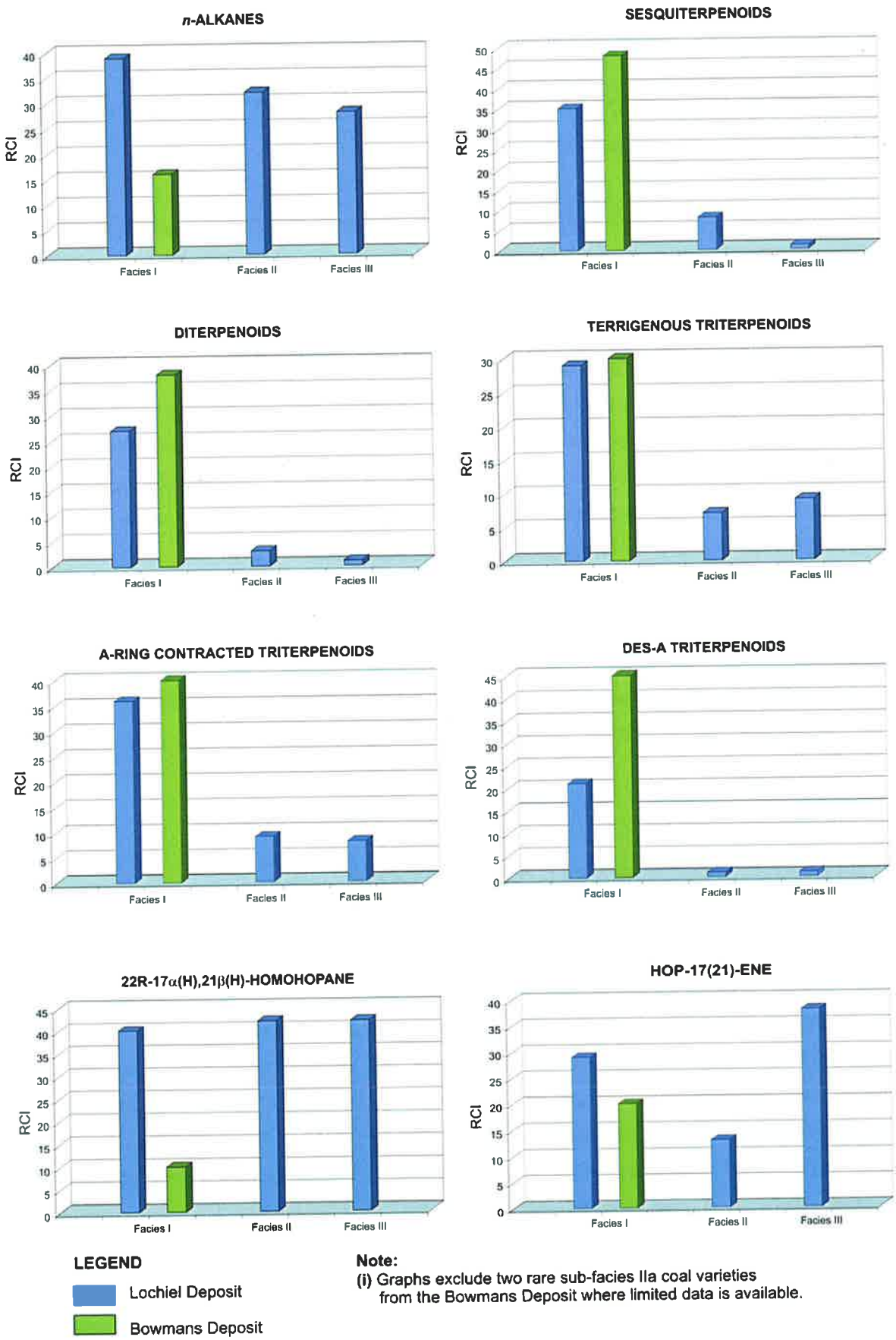



Figure 8.16 Variation of mean biomarker abundances with facies and deposit

It is noteworthy that most of these anomalies occur in Bowmans coals, despite the deposit otherwise having a more uniform biomarker content in line with its limited facies diversity. In

contrast, the Lochiel coals, which are more variable with respect to facies attributes and compound abundance, appear less prone to anomalous occurrences.

#### 8.2.9.3 Inter-deposit comparison

Facies I coals are common to both Lochiel and Bowmans, yet their biomarker characteristics are not necessarily uniform between the two deposits (Figure 8.16). The most prominent inter-deposit biomarker variation relates to 22R-17α(H),21β(H)-homohopane levels, which are approximately four times higher at Lochiel. Other compound classes showing significant differences in abundance between the deposits include the *n*-alkanes and tetracyclic diterpenoids (approximately two times greater at Lochiel), des-A triterpenoids (approximately two times higher at Bowmans) and saturated sesquiterpenoids (approximately four times more abundant at Bowmans). More subtle differences are evident in the total sesquiterpenoids, diterpenoids and various terrigenous triterpenoids which are slightly more abundant at Bowmans, whereas hop-17(21)-ene is slightly less abundant.

The apparent deposit specificity shown by a number of individual compounds within the sesquiterpenoid, diterpenoid and des-A triterpenoid classes is not universal, although several were detected in multiple coals from one deposit. Typically this phenomenon is evident only in the Bowmans coals where they often, although not exclusively, parallel increased biomarker concentrations.

## 8.3 PALAEOENVIRONMENTAL IMPLICATIONS

### 8.3.1 Comparative Evaluation

The aforementioned biomarkers provide an effective means of assessing the relative inputs of conifers, flowering plants and bacteria to each facies and deposit. This was achieved by plotting the summed abundance of the major conifer-derived sesquiterpenoids and diterpenoids relative to the dominant bacterial biomarker (22R-17α(H),21β(H)-homohopane), against the summed abundance of the major angiosperm biomarkers (terrigenous triterpenoids and their modified A-ring derivatives) relative to 22R-17α(H),21β(H)-homohopane. This method follows the principles applied by Killops *et al.* (1995) and Bechtel *et al.* (2002) when evaluating the relative contributions of gymnosperms and angiosperms to the coals and/or source rocks of the Taranaki Basin and Austrian Alps, amended by incorporating 22R-17α(H),21β(H)-homohopane for which a direct bacterial link has been postulated (Chaffee *et al.*, 1986).

The resulting cross plot clearly differentiates the three primary facies, as well as highlighting some individual sub-facies and coals of the Lochiel and Bowmans Deposits. Six associations are evident (Table 8.17; Figure 8.18). The ratios of higher plant to bacterial biomass are lowest in the Lochiel facies III coal and progressively increase through Lochiel facies II, Lochiel facies I (with sub-facies Ia highest), Bowmans sub-facies IIa-3, Bowmans facies I and ultimately Bowmans sub-facies IIa-2.

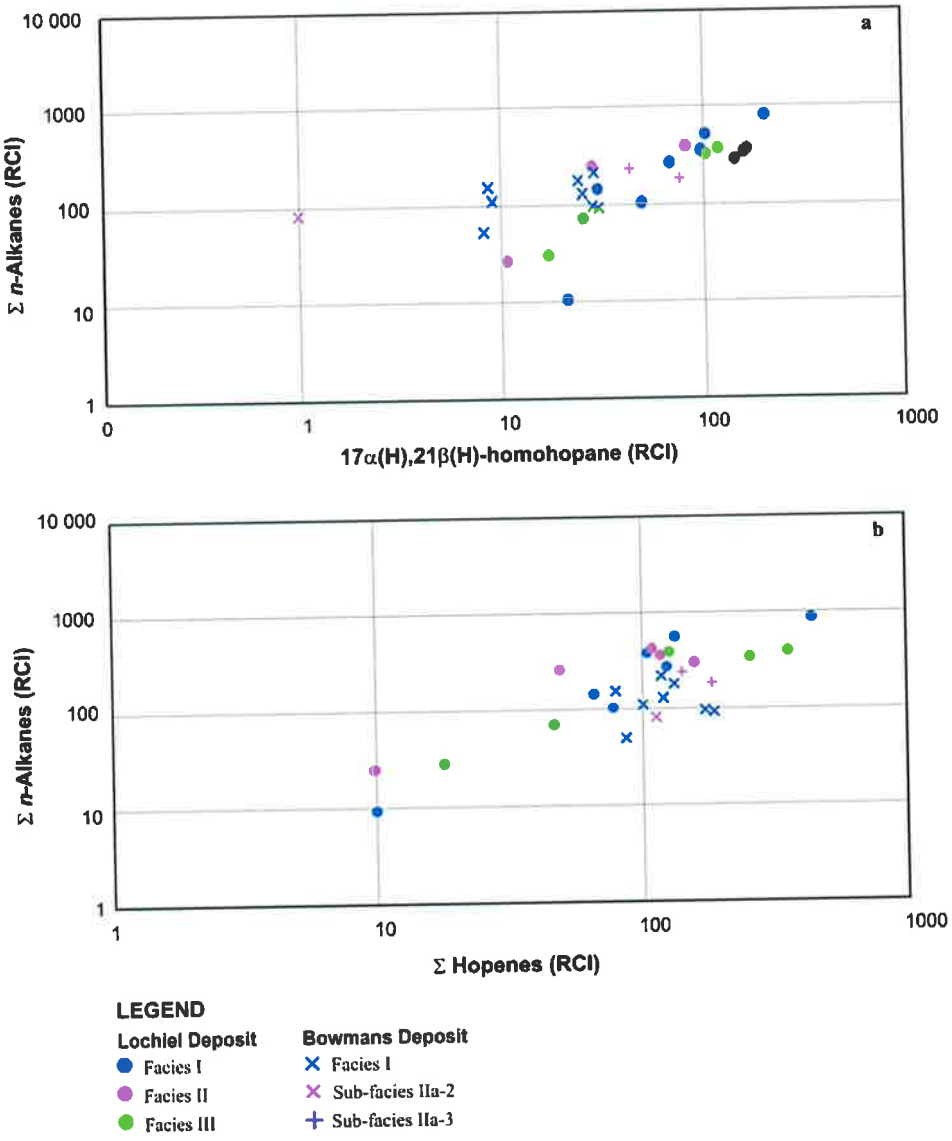



Figure 8.17 Relationship between the dominant hopanoids and total *n*-alkane abundance

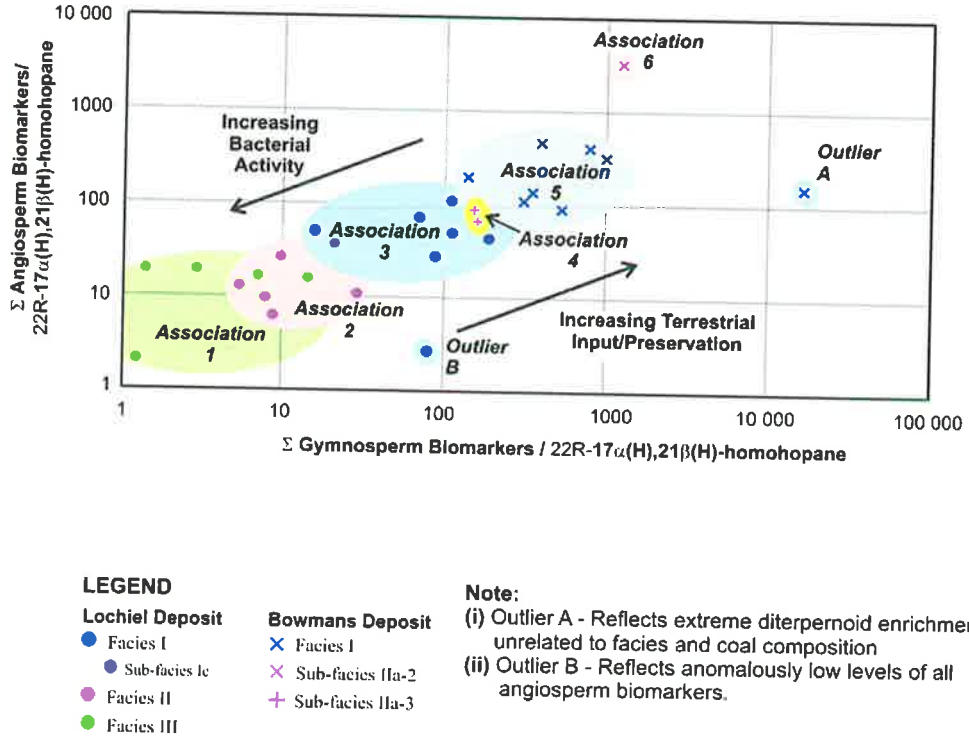



Figure 8.18 Angiosperm and gymnosperm input relative to bacterial contribution

Table 8.17 Source affinity of coal facies based on the relative abundances of gymnosperm (conifer), angiosperm and bacterial biomarkers (based on Figure 8.18)

| Association | Deposit/Facies | Gymnosperm Contribution | Angiosperm Contribution | Bacterial Contribution | Key Factor |
|---|---|---|---|---|---|
| 1 | Lochiel facies III | Very low | Low | High | Low terrestrial input |
| 2 | Lochiel facies II | Very low | Low | High | Low terrestrial input |
| 3 | Lochiel facies I | High (especially in sub-facies Ia) | High | High | High terrestrial input |
| 4 | Bowmans sub-facies IIa-3 | High | High | Moderate | High terrestrial input |
| 5 | Bowmans facies I | High | High | Moderate | Reduced bacterial input |
| 6 * | Bowmans sub-facies IIa-2 | High | High | Low | Low bacterial input |

Key * Only one sample was available from this sub-facies and it contains an anomalously low concentration of 22R-17α(H),21ß(H)-homohopane

While perhaps glossing over many of the complex issues that affect compound abundance and preservation, this integrated assessment of biomarker data agrees well with the petrographic differentiation of the three primary facies. However, biomarker evaluation is less precise for sub-type discrimination, especially for coals formed from a common source material (e.g. facies I varieties). Alternatively, such poor geochemical differentiation of sub-facies within a given facies could also be interpreted as confirming their close genetic relationship.

### 8.3.2 Facies and local palaeoenvironments

Facies I coals corresponding to biomarker associations 3 and 5 (from Lochiel and Bowmans, respectively) are rich in both angiosperm and gymnosperm (conifer) detritus that supported less bacterial activity in the peat bog than was the case for the precursor peats of other facies. Gymnosperms were the major contributors of higher plant biomass to this facies (Figure 8.18). The observed biomarker assemblage is consistent with a terrestrial forest setting, representing the principal site of plant growth and peat accumulation, and the mixed angiosperm and gymnosperm forests inferred from palaeobotanical investigations (Meakin, 1985; Manuel, 1988; Rowett, 1992; Stoian, 2003).

The origin of the contentious pale coals (i.e. sub-facies Ic; Figure 8.18) is not particularly illuminated by biomarker data. Their diterpenoid and sesquiterpenoid levels are generally low relative to other facies I varieties, although resinite is significantly enriched in this sub-facies. This unusual biomarker distribution could possibly be interpreted as reflecting a diminished conifer input in association with intense aerobic bacterial activity. Their contents of hopanoids and angiosperm-sourced triterpenoids are similar to those of other facies I coals.

Facies II and III coals (biomarker associations 1 and 2) contrast markedly with those of facies I coals in having much lower abundances of terrestrial biomarkers and possibly also slightly increased levels of bacterial hopanoids. Moreover, there tends to be a slight excess of angiosperm over gymnosperm markers, especially in association 1 (Figure 8.18). A setting with an elevated groundwater table and devoid of large trees would explain the observed characteristics, while the development of anoxic conditions would have resulted in more intense bacterial degradation of the terrestrial detritus.

The somewhat narrower range of angiosperm biomarker abundances across the facies spectrum (compared to that of the gymnosperm-sourced compounds; Figure 8.18) may reflect the persistence of smaller angiosperms into the wetter environments, whereas gymnosperms appear to be more prolific in the comparatively drier, facies I forest settings. Furthermore, the input of fine allochthonous angiosperm detritus to facies III environments may have been appreciable. Alternatively, incursion of brackish waters in the mire may occasionally occur during the more aquatic facies II/III phases (as noted by Holdgate *et al.*, 1995, in Gippsland Basin coals). Such events could lead to conditions suitable for enhanced formation and/or preservation of oleanenes (Murray *et al.*, 1997) and thus a relative increase in the angiosperm over gymnosperm biomarkers.

The remaining coals differentiated by biomarker data (associations 4 and 6) represent uncommon sub-facies IIa varieties and reflect atypical depositional conditions at Bowmans. Although showing some petrographic characteristics suggestive of elevated groundwater levels, association 6 is distinguished by extremely low levels of 22R-17$\alpha$(H),21$\beta$(H)-

homohopane. This may represent an accentuation of the low 22R-17α(H),21β(H)-homohopane levels generally present in Bowmans facies I coals, in combination with some additional local factors (e.g. atypical Eh or build up of bacteriocides such as humic acids) that hinder bacterial activity and/or the preservation of bacterial biomass. Association 4 clearly exhibits terrestrial characteristics and may represent a unique local setting within the forest peat, possibly rich in hypautochthonous matter.

Limited biomarker data are available for facies IV coals and their interpretation is somewhat inconclusive. This is because the distinction between primary geochemical characteristics and features relating to peat modification is difficult. However, the fact that outlier biomarker abundances were noted (Figure 8.18) is considered generally supportive of atypical formation mechanisms.

### 8.3.3 Regional setting

Significant differences in the biomarker characteristics of the two deposits strengthen the conclusion from petrographic and sedimentological studies that the coal-forming conditions at Lochiel and Bowmans were quite distinct.

While they share similar levels of angiosperm and gymnosperm biomarkers, differentiation of the Bowmans facies I coals (association 5) from their Lochiel equivalents (association 3) is due to the significantly lower levels of the key bacterial marker 22R-17α(H),21β(H)-homohopane in the former. This feature may be an indication of generally less intense bacterial activity at Bowmans, or increased levels of anaerobic over aerobic microbial activity relative to Lochiel. The generally oxic conditions in the forest peat at Lochiel (leading to increased tissue breakdown and formation of liptinite-enriched sub-facies Ic coals), combined with much higher 22R-17α(H),21β(H)-homohopane/hop-17(21)ene ratios (suggested by Bechtel *et al.*, 2004 to be a possible indicator of aerobic versus anaerobic bacterial activity), support the latter scenario. This in turn is consistent with petrographic evidence of a fluctuating water table and commonly aerobic conditions at Lochiel, compared to more stable conditions at Bowmans.

Inter-deposit differences also exist in *n*-alkanes, tetracyclic diterpenoids, des-A triterpenoids and sesquiterpanes. Importantly, while the precise causes of these variations are unclear, they do imply a broad change in palaeoenvironmental setting. Factors such as groundwater level, relative marine proximity, sulphate supply, pH and Eh may have been involved and influenced the microbial regime and biolipid preservation.

The relatively consistent ratio of angiosperm to gymnosperm biomarkers across facies and deposits suggests that a mixed forest persisted during coal accumulation throughout the

region. This finding is in line with the results of previous palaeobotanical studies of palynomorphs (Meakin, 1985; Rowett and Stoian, 1999; Stoian, 2003), fossil wood (Manuel, 1988) and dispersed cuticle (Rowett, 1992) in the Tertiary sediments of the northern St. Vincent Basin.

## 8.4 SIGNIFICANCE FOR BROWN COAL BIOMARKER STUDIES

This pioneering organic geochemical investigation of the Lochiel and Bowmans Deposits has generated extensive data sets pertaining to biomarker occurrence and distribution in Tertiary brown coals. Although outside the main focus of the present research, some issues that may be relevant to the evaluation of brown coal biomarkers elsewhere are briefly outlined below.

### 8.4.1 Preservation of A-ring-contracted and des-A triterpenoids

The occurrence of several A-ring-contracted triterpenoids in Lochiel and Bowmans coals contrasts markedly with the findings of previous reports of brown coals where these compounds are rare and occur in low concentrations relative to regular triterpadienes (ten Haven *et al.*, 1992a). Des-A triterpenoids also appear to be more extensive at Lochiel and Bowmans than in other brown coal deposits (Stout, 1992).

Optimum conditions for the preservation of these triterpenoids appear to have existed in both deposits, involving either the presence of a source particularly rich in appropriate precursors, or other factors promoting their formation and preservation. Murray *et al.* (1997) proposed a mechanism for the enhanced preservation of terrigenous triterpenes, involving marine incursion during early diagenesis. High sulphur contents and concentration profiles indicative of such marine influence following peat accumulation occur at both Lochiel and Bowmans (see Section 9.4) and may have contributed to the observed phenomena.

### 8.4.2 Unusual distribution of 22R-17α(H),21β(H)-homohopane

The abundance of 22R-17α(H),21β(H)-homohopane is uniformly high in all coal types, with the notable exception of facies I at Bowmans (Table 8.15; Figure 8.16). This lack of correlation between the principal bacterial biomarker and facies is interesting. Since biochemical gelification increases markedly from facies I to facies II/III it might be expected that bacterial activity would vary considerably between the relatively oxic and anoxic environments of facies I and facies III, respectively.

### 8.4.3 Other issues

The distribution of higher plant and bacterial biomarkers in the Lochiel and Bowmans coals highlights the degree to which variations can occur within and between coal types and this in turn has implications for the way these compounds can be used for palaeoenvironmental reconstruction. For example, diterpenoids commonly employed as conifer markers can occur in almost negligible quantities within facies I coals which are unlikely to have been derived solely from angiosperm vegetation. Conversely, their extreme enrichment can occur independently of coal composition. Although most pronounced in the gymnosperm-derived terpenoids, significant intra-facies variation can also exist in the more uniformly distributed biomarkers such as the hopanoids and the angiosperm-derived triterpenoids. Extreme caution is therefore required when drawing specific facies and palaeoenvironmental inferences from small sample sets or using individual biomarkers in isolation.

Although facies-related variations in biomarker abundance exist indicating gross change with coal composition, only tenuous links could be established to specific macerals or maceral assemblages. Of particular note is the limited correlation of sesquiterpenoids and diterpenoids with resinite (especially in the terrestrial coals) and of *n*-alkanes with cutinite.

A moderate correlation also is evident between high-molecular-weight *n*-alkanes and 22R-17α(H),21β(H)-homohopane, even although they are sourced from quite different constituents, viz. bacterial membranes (Chaffee *et al.,* 1986) and cuticular waxes (Hazai *et al.,* 1988; Wang and Simoneit, 1990; Peters and Moldowan, 1993). A similar correlation is apparent between the hopenes and *n*-alkanes. In contrast, *n*-alkane levels appear unrelated to the abundance of gymnosperm and angiosperm biomarkers.

## 8.5 SUMMARY

The principal biomarker groups identified in the aliphatic hydrocarbon fraction of the Lochiel and Bowmans coals are *n*-alkanes showing a strong odd/even predominance; extensive suites of gymnosperm-derived sesquiterpenoids and diterpenoids; bacterial hopanoids (including moretanes, hopenes and hopanes) and assorted angiosperm-sourced compounds with oleanene, lupene and ursene skeletons, together with their ring-A contracted and des-A derivatives. Steroids represented by $C_{29}$ sterenes and diasterenes were also recognised. Although all these compound classes have previously been reported in brown coals, some departures from their typical occurrence and distribution were noted. In particular, sesquiterpenoids, diterpenoids and the modified terrigenous triterpenoids are more diverse while A-ring-contracted triterpenoids are significantly more abundant. The enhanced formation and preservation of some compound classes may be associated with marine influence during early diagenesis.

The occurrence of many individual sesquiterpenoids, diterpenoids and des-A triterpenoids is highly erratic, being detected in only a few samples and, in some cases, just one deposit (viz. Bowmans). In contrast, intact triterpenoids, A-ring-contracted triterpenoids, hopanoids and steroids display a relatively even distribution and abundance. Instances of anomalous, facies-independent enrichment of multiple compounds in a given class of biomarkers were also detected, especially at Bowmans.

The concentrations of gymnosperm and angiosperm biomarkers are typically highest in facies I coals, and low to negligible in facies II and III. Sesqui- and diterpenoid hydrocarbons provide the highest degree of facies differentiation. By way of contrast, there is only very minor change in the concentrations of hopanoids and *n*-alkanes across the coal suite, with a very subtle increase from facies I to III.

The abundances of gymnosperm and angiosperm-sourced terpenoids, relative to the bacterial marker 22R-17α(H),21β(H)-homohopane, can be employed to identify six biomarker associations which correspond to petrographically-defined facies and deposit groupings. However, biomarker data are less effective in discriminating between sub-facies. The palaeoenvironmental inferences based on biomarkers largely concur with the petrographic evidence in suggesting a mixed gymnosperm-angiosperm forest setting for facies I, with significantly lower terrestrial inputs and slightly increased bacterial activity in facies II and III. The latter inferences are consistent with higher groundwater levels (favouring smaller water tolerant angiosperm species over gymnosperms) and open water settings, respectively.

While similar biomarker classes occur in both deposits, significant differences in abundance are evident for several compound classes and sub-classes. For comparable coals, terrestrial plant biomarkers are more abundant at Bowmans, while the key bacterial biomarker 22R-17α(H),21β(H)-homohopane, is noticeably less abundant relative to hop-17(21)ene. Furthermore, the more persistent anoxicity during peat diagenesis at Bowmans (relative to Lochiel) is likely to have favoured increased biomarker preservation. Although the precise mechanisms are unclear, findings at a molecular level tend to corroborate petrographic observations, both line of investigation highlighting fundamental differences in the peat-forming conditions between Lochiel and Bowmans.

# 9 QUARTZ, KAOLINITE AND SULPHUR DISTRIBUTIONS

The inorganic constituents of the Lochiel and Bowmans coals include crystalline mineral matter (detrital and authigenic) and various ionic species (bound to the kerogen and dissolved in pore water). Sulphur may be present in sulphide minerals (inorganic S) and as a hetero-element in the kerogen of the coal (organic S). Crystalline minerals, particularly authigenic species that form during peat accumulation, are potentially useful for palaeoenvironmental evaluation and are the focus of this chapter. The major syndepositional minerals in the coals of the northern St. Vincent Basin, quartz and kaolinite, are initially assessed with regard to their lateral and vertical distribution within seams, their relationship to coal facies and their regional distribution. From this exercise, inferences are drawn about the regional setting, the relative importance of detrital and authigenic sedimentation in each deposit and the local depositional environments. A brief review of sulphur content, widely regarded as a measure of marine proximity during and immediately after peat accumulation (Westgate and Anderson, 1984; Teichmuller 1989; Holdgate *et al.*, 2000) concludes the chapter.

## 9.1 CRYSTALLINE MINERAL SPECIES AND OCCURRENCE

The major mineral species in the Lochiel and Bowmans coals are quartz and kaolinite, along with marcasite and pyrite in somewhat lower concentrations and minor amounts of zircon and rutile (Readett and Quast, 1987; Manuel and Quast, 1990; Quast and Readett, 1991; Table 9.1). However, considerable variation exists in the nature, size and distribution of mineral species throughout seams.

Table 9.1 Mineralogy of Lochiel and Bowmans coals (after Readett and Quast, 1987; Manuel and Quast, 1990)

| Abundance | Mineral | Occurrence |
|---|---|---|
| Major | Quartz | Generally >10 μm and occasionally >1mm, commonly rounded to subangular. Occasional small crystalline grains <10 μm detected. |
| | Kaolinite | Generally smaller than quartz. Ranges from particles <5 μm to granular aggregates of 500 μm. |
| | Marcasite and pyrite | Marcasite dominant, with assorted forms including (i) discrete, euhedral, (ii) granular and dendritic aggregates, and (iii) pseudomorphs of granular and cellular organic material |
| Minor | Zircon and rutile | Small, mostly <50 μm subangular particles |
| Trace | Phosphates, calcite, muscovite, lead, zinc and tin sulphides, jarosite, various silicates, leucite | |

Quartz occurs mainly as rounded to subangular and irregularly shaped particles, typically ranging in size from 100 μm to 1 mm (Readett and Quast, 1987; Manuel and Quast, 1990; Ward, 1992). These appear to be predominantly detrital, although some small (<10 μm)

particles with a well-developed crystalline habit were interpreted as authigenic (Manuel and Quast, 1990; Ward, 1992). In the B1 Seam at Bowmans, Ward (1992) found the latter to be particularly prominent. At the macroscopic scale, quartz is in places visible as fine to medium grained quartz sand and silt, which are most prevalent near seam interfaces and in wood-rich sub-facies Ia coals. Various modes of occurrence have been recognised including evenly disseminated grains, discontinuous laminae, thin regular beds (1-2 grains thick), and variously shaped and orientated pod and vein-like occurrences.

Kaolinite occurs principally as discrete well-rounded particles less than 5 μm in size, which in places form loose aggregates 0.5 to 1 mm across (Manuel and Quast, 1990). The majority of the kaolinite particles are interpreted as detrital, although some associated with relic pore space are most likely authigenic. Ward (1992) noted that kaolinite in South Australian Tertiary coals is typically poorly crystallised and hence largely detrital in origin.

Of the other mineral species, pyrite and marcasite occur as discrete particles and occasionally as granular aggregates, or dendritic particles (Manuel and Quast, 1990) and represent authigenic mineralisation. Rutile and zircon are only rarely detected and occur as discrete detrital grains typically <20 μm in size.

The dominance of quartz, along with kaolinite as the main clay mineral, in sediments comprising the initial fill of the St. Vincent Basin was interpreted by Stuart (1969) to infer highly weathered source rocks.

## 9.2 QUARTZ AND KAOLINITE DISTRIBUTION

The concentrations of quartz and kaolinite vary markedly within individual seams, from one seam to the next, and laterally across both deposits. Evaluation of these minerals and their distribution is based on estimates derived from analytically determined $Al_2O_3$ and $SiO_2$ levels in coal ash and assay quartz values from raw coal. The estimation procedure and its limitations are outlined in Chapter 3 and Appendix E1.

### 9.2.1 Gross seam abundances

The average estimated quartz and kaolinite contents of the major seams are summarised in Table 9.2. While some caution is necessary in evaluating gross seam averages because of the significant lateral variations in mineral abundance (see Sections 9.2.2 and 9.2.3), these estimates highlight the fact that the Bowmans coals are clearly more siliceous than those in the Lochiel Deposit. Furthermore, they are consistent with the major inter-seam fluctuations documented from quantitative mineral evaluations by Readett and Quast (1987); and they are supported by $SiO_2$ and $Al_2O_3$ analyses.

Table 9.2 Average mineral contents and ash composition for each seam

| Mineral Content & Ash Composition | Lochiel Deposit | | | Bowmans Deposit | | |
|---|---|---|---|---|---|---|
| | F Seam | G Seam | H Seam | B1 Seam | B3 Seam | C Seam |
| Quartz (% db) * | 2.8 | 2.5 | 10.6 | 6.5 | 5.1 | 5.0 |
| Kaolinite (% db) * | 8.6 | 3.5 | 4.0 | 4.0 | 2.5 | 1.7 |
| Quartz/Kaolinite * # | 0.3 (0.3) | 1.1 (0.7) | 3.3 (2.7) | 1.7 (1.6) | 2.2 (2.0) | 3.6 (2.9) |
| $SiO_2$ (% db) * | 36.7 | 26.7 | 58.2 | 39.1 | 34.6 | 31.8 |
| $Al_2O_3$ (% db) * | 20.7 | 13.0 | 8.7 | 9.5 | 6.2 | 4.7 |
| $SiO_2/Al_2O_3$ *# | 1.8 (1.8) | 2.9 (2.1) | 8.6 (6.7) | 4.6 (4.1) | 6.1 (5.6) | 8.8 (6.8) |

Key: % db = weight percent, dry-coal basis
* Values for mineral and ash composition content, and ratios represent seam averages, calculated using all individual full seam core analyses (e.g. ~120 G Seam boreholes at Lochiel and ~30 C Seam boreholes at Bowmans)
# An additional ratio calculated from the mineral and ash composition seam averages is show in brackets

In the Lochiel Deposit estimated mineral abundances differ markedly between seams, with an upward trend of increasing kaolinite (and $Al_2O_3$) levels and a corresponding reduction in the quartz/kaolinite ratio (Figures 9.1 and 9.2; Table 9.2). The basal H Seam is mineral rich and quartz dominated, while the overlying G Seam is mineral poor with a slight excess of quartz over kaolinite. The mineral content increases again to moderate levels in the uppermost F Seam which has a kaolinite-dominated mineralogy.

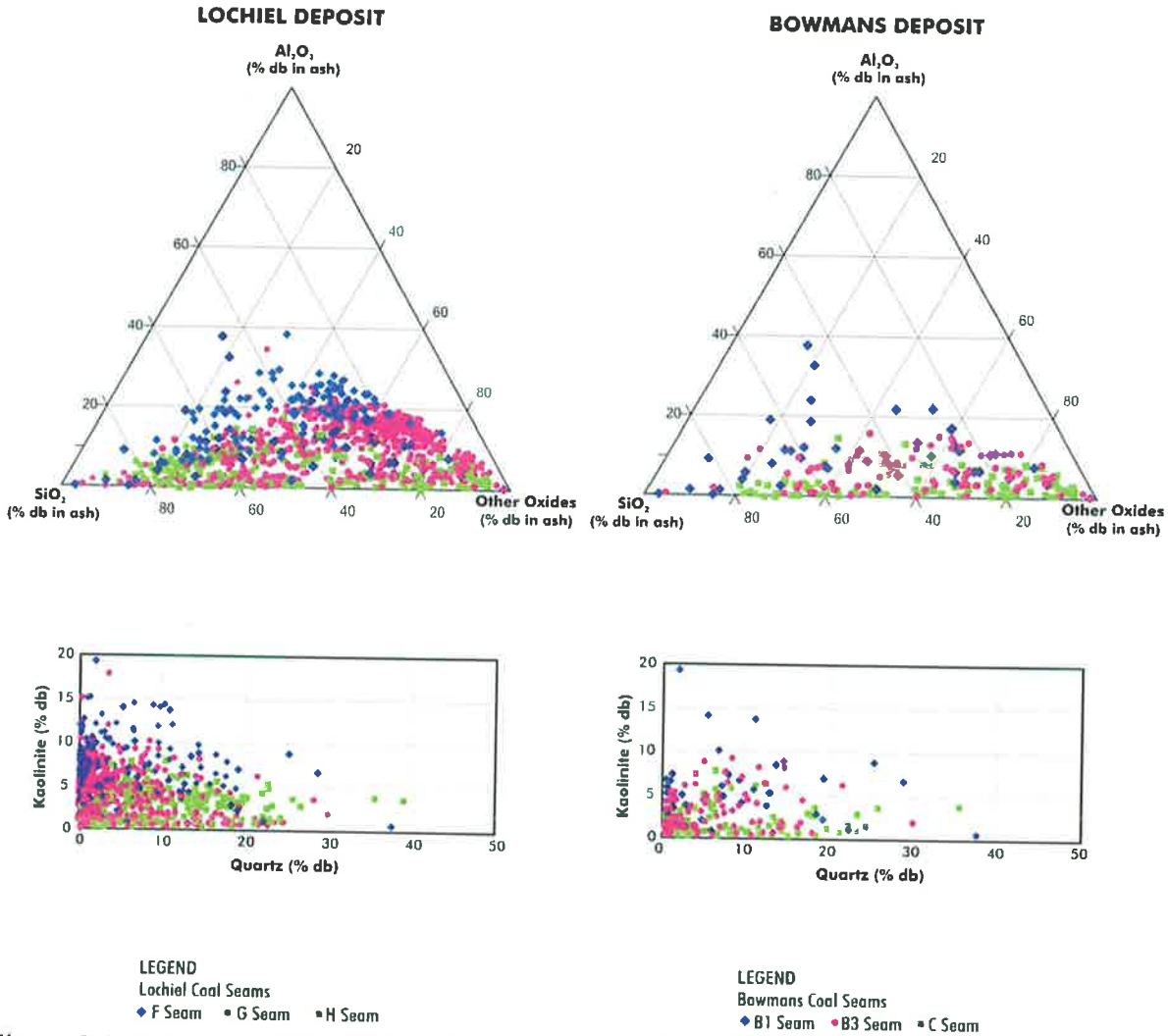
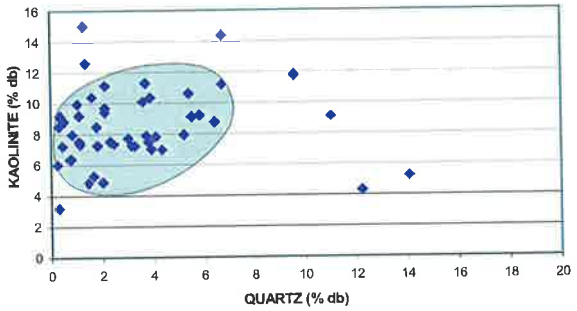



Figure 9.1 Ash composition and estimated quartz and kaolinite content by seam and deposit

Upwardly increasing kaolinite levels through the coal sequence are also a feature of the Bowmans Deposit, along with a relatively consistent quartz content (Figures 9.1 and 9.2; Table 9.2). However, all its seams have a predominantly quartzitic mineralogy. Decreasing quartz/kaolinite ratios up sequence are paralleled by a general increase in total mineral matter.

Comparison of the relative mineral abundances at Lochiel and Bowmans reveals some notable differences. Coals in the latter deposit are considerably more quartzitic than those from the Lochiel Deposit (with the notable exception of H seam; Table 9.2). Significantly, the highest kaolinite abundance at Bowmans (i.e. B1 Seam) is approximately equivalent to the minimum at Lochiel (i.e. G Seam; Table 9.2). Other notable inter-deposit differences include a more consistent quartz/kaolinite ratio in the Bowmans seams, compared to a major up-sequence decrease at Lochiel.

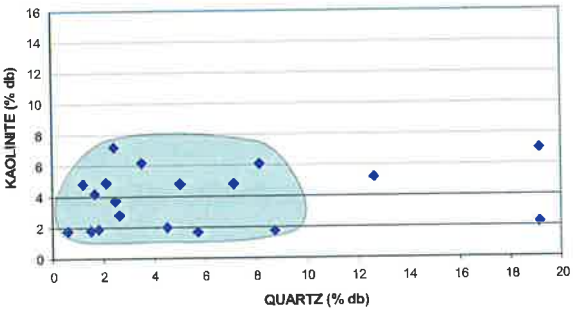
**LOCHIEL DEPOSIT - F SEAM**




**SUMMARY STATISTICS**

| | Est. Quartz | Est. Kaolinite |
|---|---|---|
| Samples: | 49 | 49 |
| Minimum: | 0.2 | 3.2 |
| Maximum: | 14.1 | 15.0 |
| Average: | 3.3 | 8.4 |
| Median: | 2.1 | 8.0 |

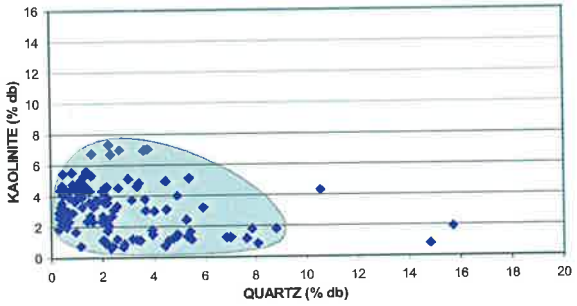
**BOWMANS DEPOSIT - B1 SEAM**




**SUMMARY STATISTICS**

| | Est. Quartz | Est. Kaolinite |
|---|---|---|
| Samples: | 20 | 20 |
| Minimum: | 0.6 | 1.7 |
| Maximum: | 28.7 | 7.2 |
| Average: | 6.9 | 4.1 |
| Median: | 4.0 | 4.5 |

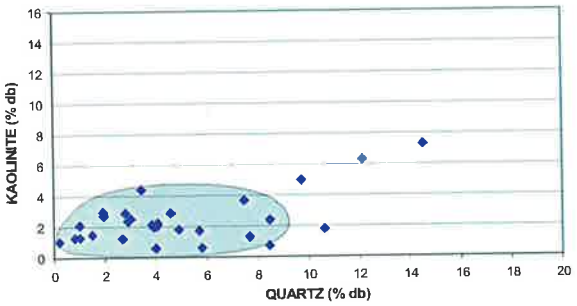
**LOCHIEL DEPOSIT - G SEAM**




**SUMMARY STATISTICS**

| | Est. Quartz | Est. Kaolinite |
|---|---|---|
| Samples: | 124 | 124 |
| Minimum: | 0.3 | 0.6 |
| Maximum: | 15.7 | 7.4 |
| Average: | 2.6 | 3.2 |
| Median: | 2.0 | 3.3 |

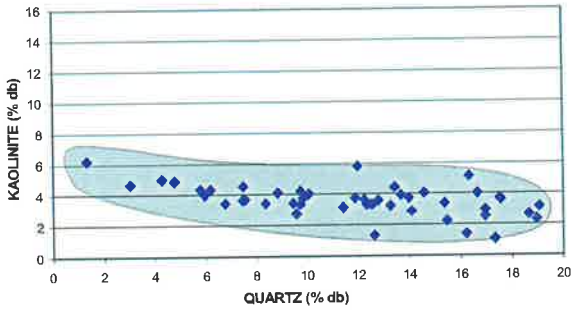
**BOWMANS DEPOSIT - B3 SEAM**




**SUMMARY STATISTICS**

| | Est. Quartz | Est. Kaolinite |
|---|---|---|
| Samples: | 29 | 29 |
| Minimum: | 0.2 | 0.6 |
| Maximum: | 14.5 | 7.3 |
| Average: | 4.9 | 2.4 |
| Median: | 4.0 | 2.1 |

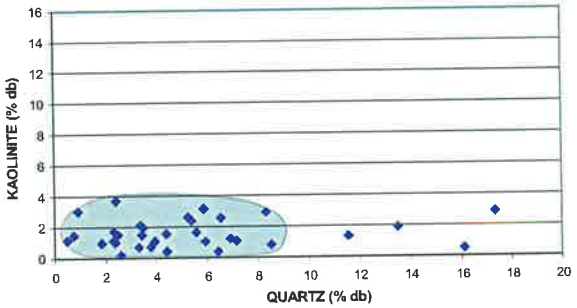
**LOCHIEL DEPOSIT - H SEAM**




**SUMMARY STATISTICS**

| | Est. Quartz | Est. Kaolinite |
|---|---|---|
| Samples: | 63 | 63 |
| Minimum: | 13 | 0.8 |
| Maximum: | 24.4 | 7.4 |
| Average: | 11.8 | 3.7 |
| Median: | 12.2 | 3.7 |

**BOWMANS DEPOSIT - C SEAM**




**SUMMARY STATISTICS**

| | Est. Quartz | Est. Kaolinite |
|---|---|---|
| Samples: | 34 | 34 |
| Minimum: | 0.5 | 0.2 |
| Maximum: | 20.9 | 3.7 |
| Average: | 5.9 | 1.6 |
| Median: | 4.4 | 1.4 |

Figure 9.2 Quartz-kaolinite cross plots by seam

### 9.2.2 Lateral variations within Lochiel seams

Major lateral mineralogical variations exist in most Lochiel seams (Figures 9.3 to 9.5). Some features are controlled by proximity to the seam margin, while others appear independent of seam thickness and have a distinctly regional character. In general, the former are commonly highlighted by the distribution of quartz, while the latter are more pronounced in the occurrence of kaolinite.

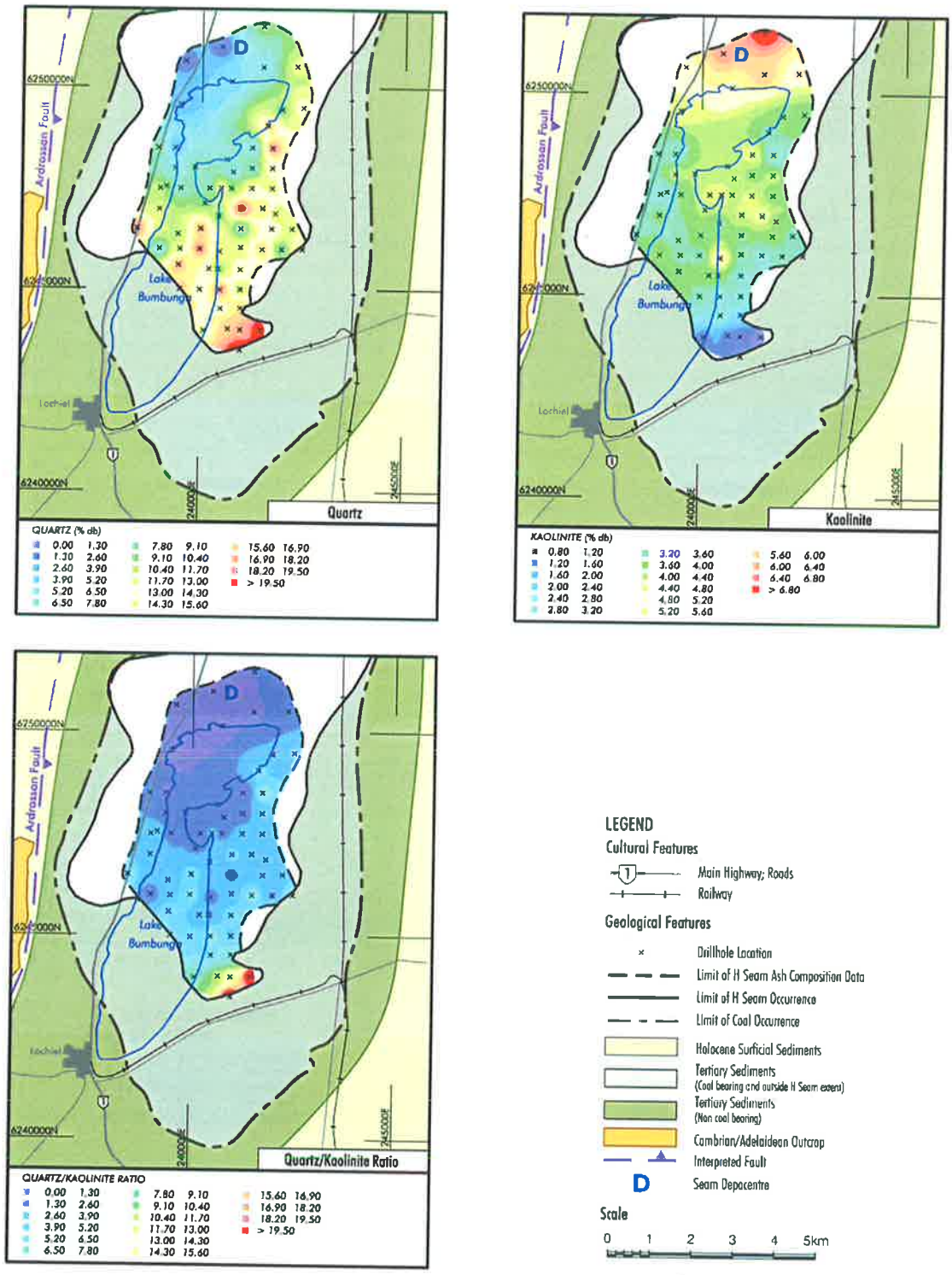



Figure 9.3 H Seam quartz and kaolinite distribution through the Lochiel Deposit

The distribution of quartz and kaolinite in H Seam contrast strongly and appear inversely related (Figure 9.3). In general, the southern half of the deposit is mineral rich and quartz dominated, while in the north the seam is characterised by moderate mineral levels and a more even mix of components. More specifically, estimated quartz levels decrease from ~15% in the southeast to <2.5% in the north northwest (broadly in line with seam thickening), the lowest levels approximately coinciding with the seam depocentre. Conversely, kaolinite shows a regular northerly increase in abundance, from <1% to approximately 7%. Significantly, the zone of maximum kaolinite abundance is slightly offset from the area of lowest quartz. Moreover, high kaolinite levels appear unrelated to coal thickness, the abundance of this clay mineral increasing as the seam thins northwards. The respective distributions of these two minerals are highlighted by the quartz/kaolinite ratio which shows a well defined regional gradient, increasing from south to north (Figure 9.3).

In G Seam the distributions of quartz and kaolinite likewise differ appreciably, displaying some similarities to the regional trends evident in H Seam (Figure 9.4). Quartz shows a broadly radial pattern with its abundance being lowest near the seam depocentre, increasing toward the seam's margins. More specifically, abundance increases from <0.5% in central settings to approximately 15% near the southeastern margin, along with a corresponding increase in grain size (Readett and Quast, 1987). In contrast, kaolinite displays a strong regional gradient and increases to the north, from <1% to approximately 7%. However, the transition between low kaolinite in the south and moderate to high levels elsewhere is relatively abrupt, while further north the increase is more gradual. The interplay of these two distribution patterns results in a quartz-dominated mineralogy in the south, with kaolinite dominant in the central and northern reaches of the deposit, consistent with the mineralogical observations of Readett and Quast (1987).

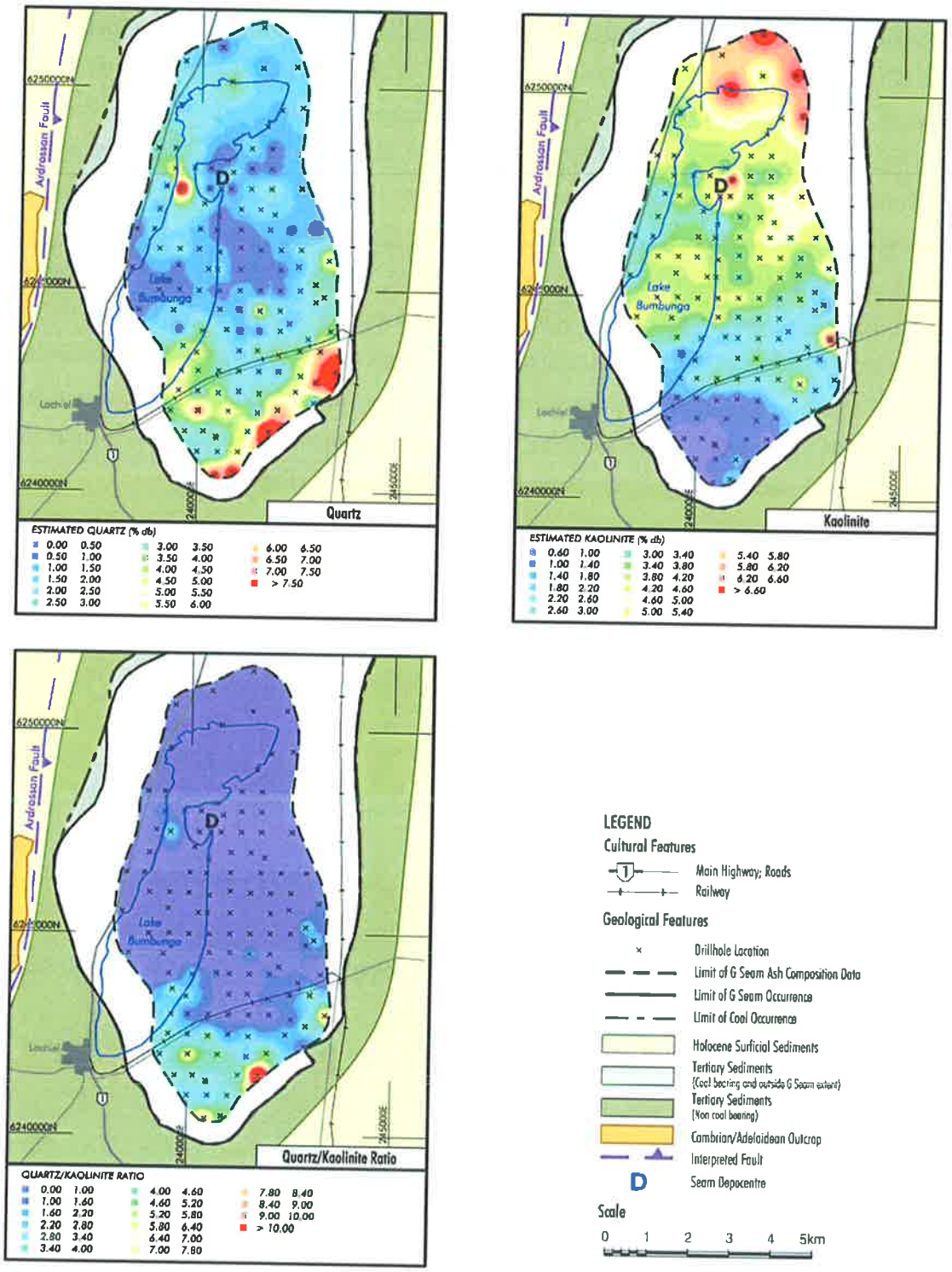



Figure 9.4 G Seam quartz and kaolinite distribution through the Lochiel Deposit

Mineral distribution in F Seam differs from that in the underlying seams. Here both major components co-vary, such that their concentration decreases toward the seam depocentre and is greatest in the south (Figure 9.5). However, this relationship is not consistent throughout the deposit and their abundance can be locally antisympathetic. Although somewhat erratic (paralleling the occurrence of the host seam; see section 4.4.1.3), the quartz content decreases northward from <5% in the southeast to <1% over much of the central and northern areas, with a further tendency to diminish away from seam margins. The kaolinite content typically exceeds 7% in the central part of the seam and increases to above 10% in the north and south.

The quartz/kaolinite ratio in F Seam is relatively consistent and generally <1 across the deposit.

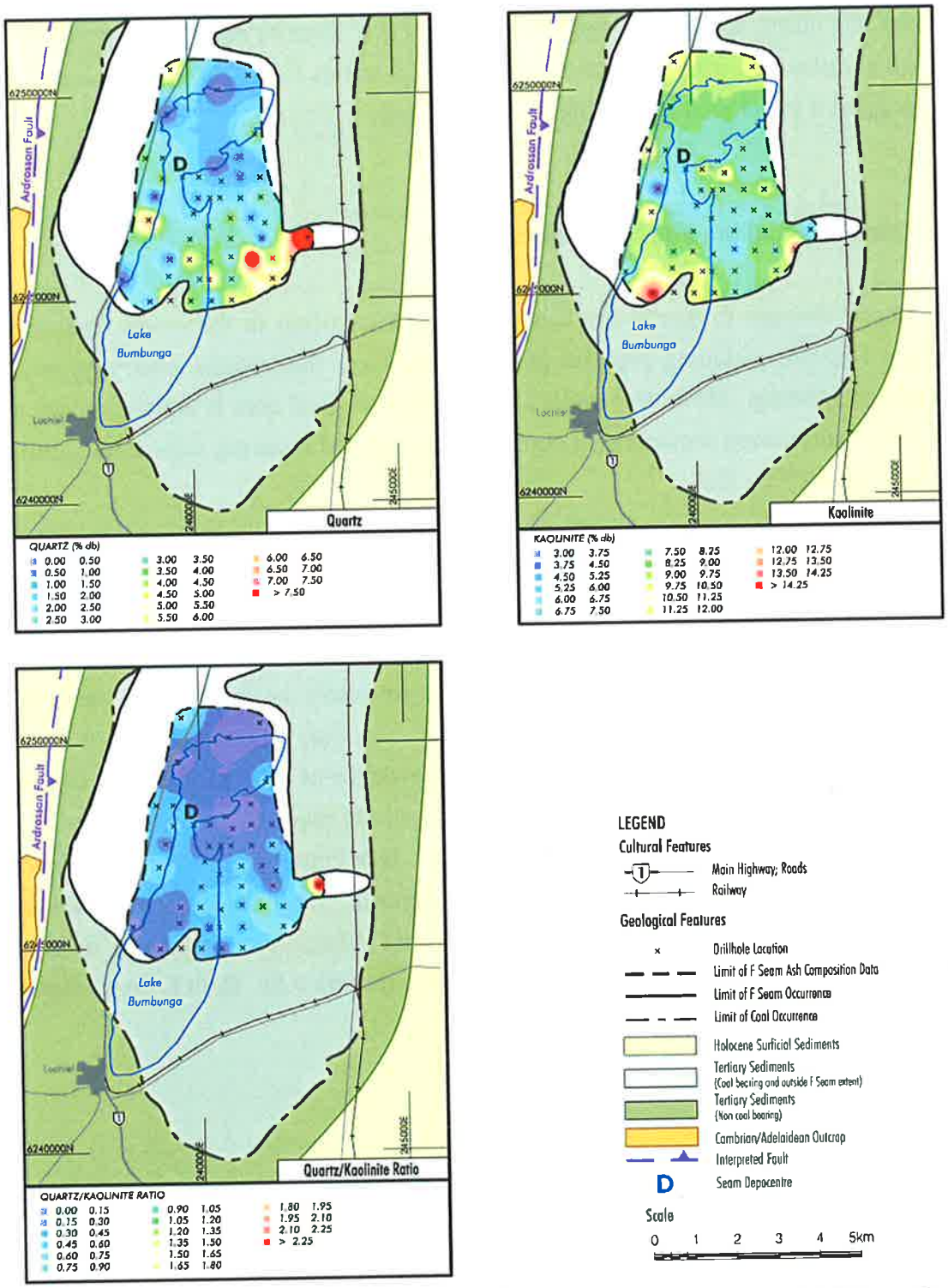



Figure 9.5 F Seam quartz and kaolinite distribution through the Lochiel Deposit

A feature common to all three seams is their elevated quartz levels in the south and the tendency for these to diminish as the seam thickens, resulting in a drop in concentration toward the depocentre. However, kaolinite occurrence is more variable. Northerly increasing gradients are evident in H and G Seams, while in F Seam, where kaolinite levels are significantly higher, the abundance increases as the seam thins. Quartz/kaolinite ratios show a

progressive change up sequence, such that the quartz-dominated portion of the seam is progressively confined to the south of the deposit. The frequently independent distributions of quartz and kaolinite suggest that differing mechanisms controlled their abundance. In particular, the quartz appears to be primarily detrital (i.e. since its abundance increases toward the seam peripheries), while well developed regional trends in kaolinite, unrelated to detrital influx suggest it is the product of authigenic processes.

### 9.2.3 Lateral variations within Bowmans seams

Major lateral changes in quartz and kaolinite abundance occur in the seams comprising the Bowmans Deposit, including regional gradients and local fluctuations associated with seam thinning and splitting. However, unlike Lochiel mineralogical data is limited to only portion of the total seam extent, focussing on seam depocentres and reducing with seam splitting and thinning (Figures 9.6 - 9.8).

Over much of C Seam an approximately inverse relationship is evident between quartz and kaolinite (Figure 9.6). The quartz content drops from >5% near the northern limit of the seam to <1% near the southern depocentre. This mineralogical gradient is locally inversely related to seam thickness, but rapid changes may occur, especially in the north as seam splitting develops. Kaolinite content broadly increases southward, from <1% near the northern limit to approximately 2.5% at several localities across the centre of the seam, before declining to ~1% at the southern depocentre. In the south, kaolinite appears to locally parallel quartz abundance. The respective distributions of these two components result in pronounced changes in the quartz/kaolinite ratio across the deposit. The mineralogy of the seam is strongly dominated by quartz in the north, with a rapid transition to moderately quartziferous centre and a weak dominance of kaolinite in the south (Figure 9.6). Both C Seam depocentres are sites of relative kaolinite enrichment.

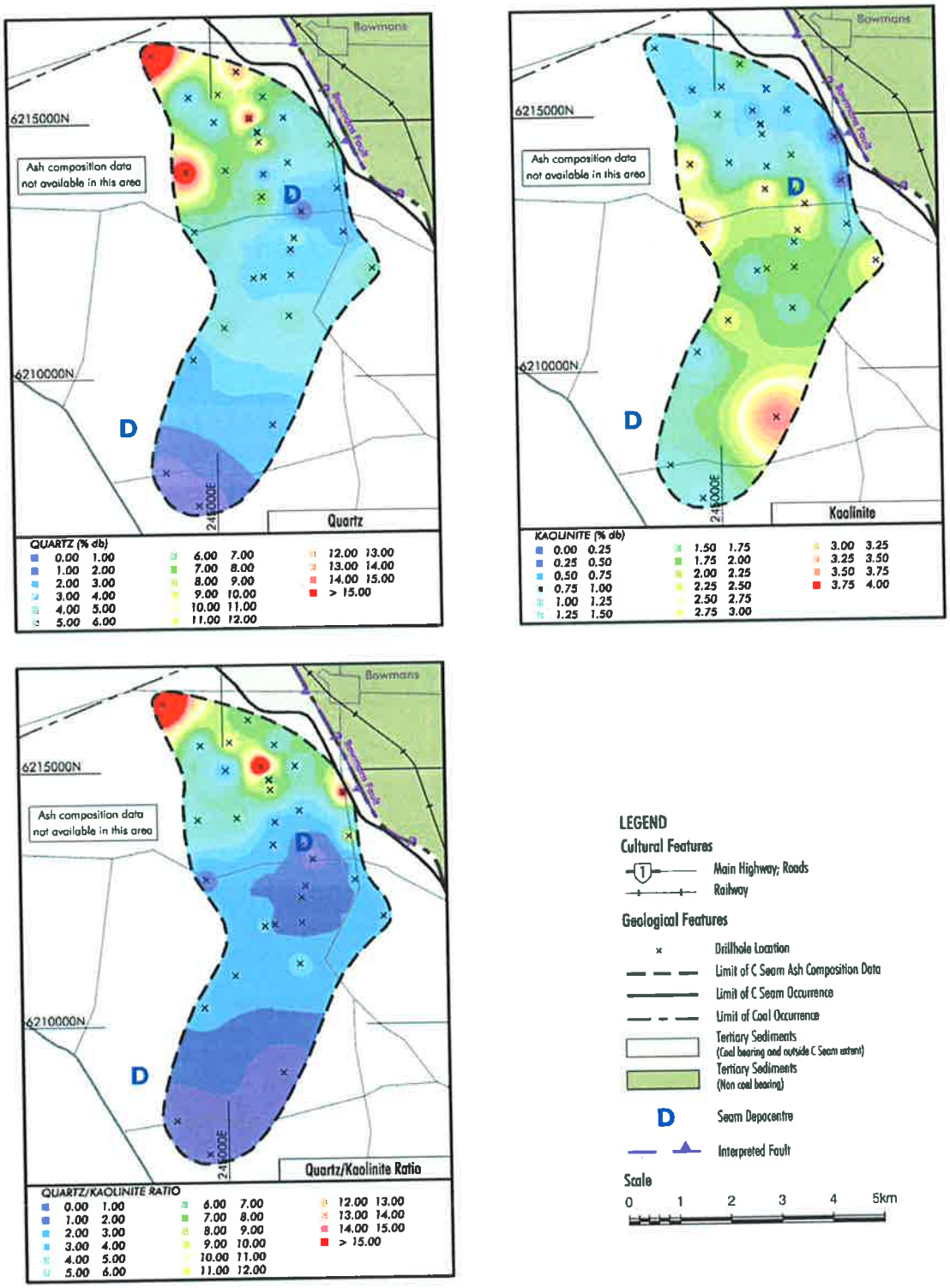



Figure 9.6 C Seam quartz and kaolinite distribution through the Bowmans Deposit

In B3 Seam quartz and kaolinite vary sympathetically over much of the northern and central regions of data coverage, although an inverse trend develops in the south (Figure 9.7). More specifically, quartz decreases from highs of ~10% in the northwest and ~5% in the south to <2.5% near the seam depocentre. Kaolinite mirrors this pattern dropping from ~5% in the north to 1.5% near the seam depocentre, but low levels (<1.5%) are maintained in the south, despite seam thinning. As a consequence the quartz/kaolinite ratio is relatively constant, with

a slight dominance of quartz over much of the seam, increasing locally in the south (Figure 9.7).

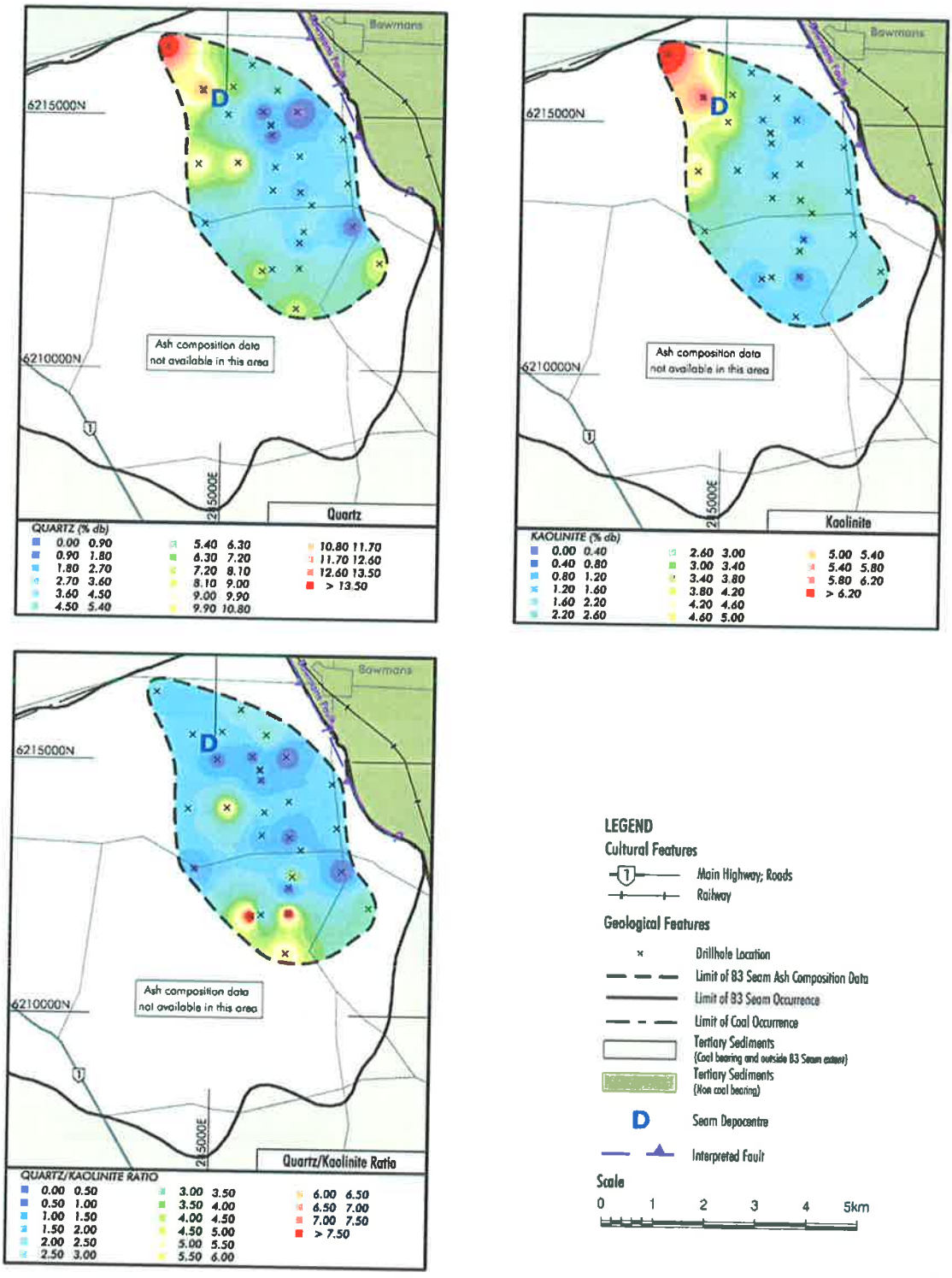



Figure 9.7 B3 Seam quartz and kaolinite distribution through the Bowmans Deposit

Quartz and kaolinite distributions appear largely independent of each other in that limited part of B1 Seam for which data are available (Figure 9.8). The abundance of quartz is consistently low (<5%) over much of this northeastern area but increases rapidly to >15% near the southern margin of the data coverage in association with splitting and thinning. It is noteworthy that low quartz levels persist to the northeast as the seam thins, albeit gradually.

In contrast, kaolinite content shows considerable variation, being lowest around the depocentre and increasing to the northwest and southeast. Overall kaolinite dominates the mineralogy of the B1 Seam in the northwest, while south of its depocentre quartz is dominant.

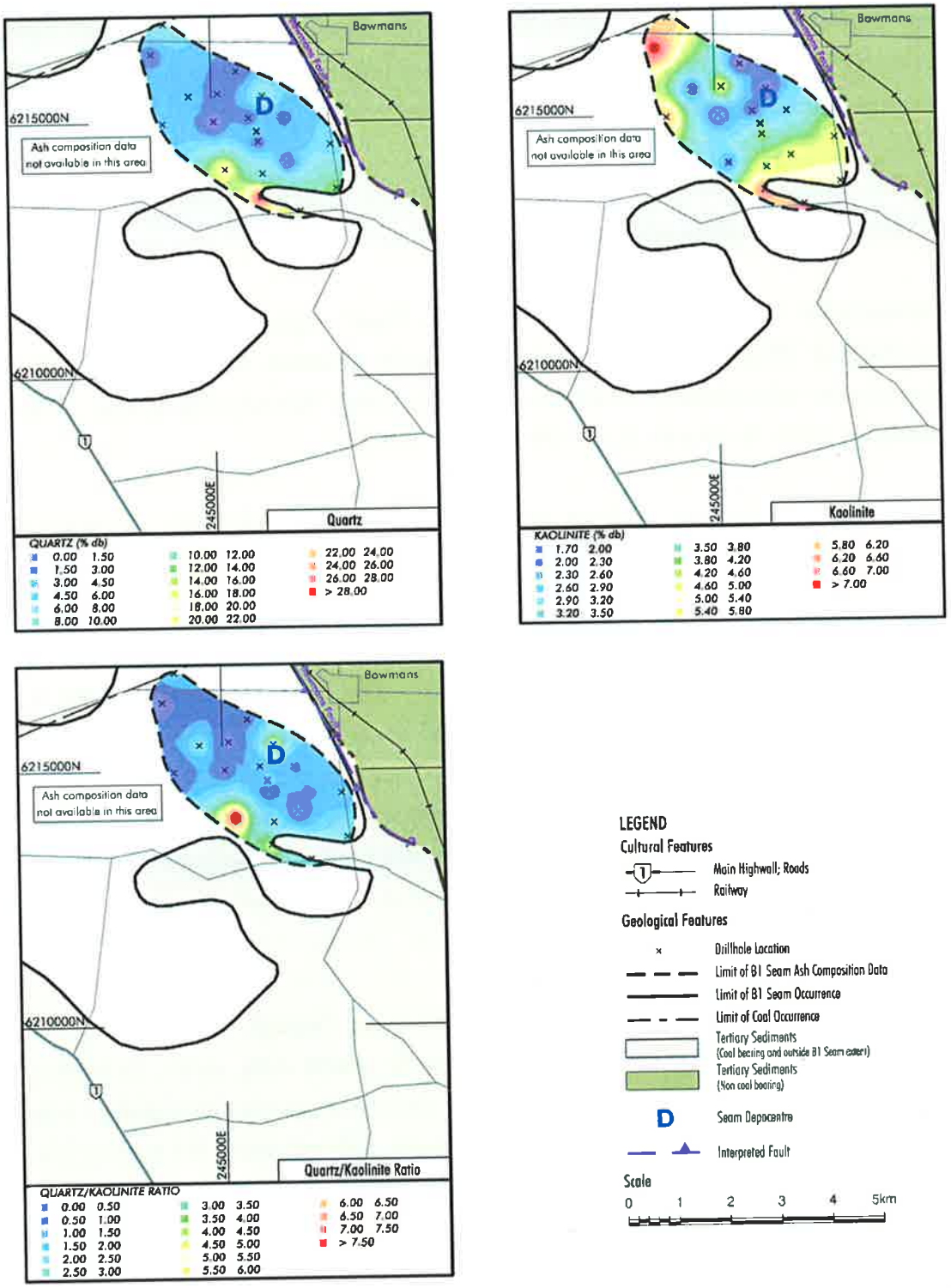



Figure 9.8 B1 Seam quartz and kaolinite distribution through the Bowmans Deposit

In each of the Bowmans seams quartz levels generally decrease away from lateral margins and zones of splitting. Transitions between areas of high and low quartz are commonly sharp and there is a major southward shift in the loci of quartz enrichment between Seams C and

B3. The pattern of kaolinite occurrence also changes upwards through the coal sequence. The principal focus of enrichment shifts from the south in the basal C Seam to the north of the deposit in both the B3 and B1 Seams. The relationship between quartz and kaolinite changes considerably, both within and between seams, with the former interpreted as predominantly detrital. However, the pattern of kaolinite occurrence appears more complex. Its enrichment is associated with thinning and splitting (where it is presumably detrital), but also near seam depocentres (where it is more likely to be authigenic).

### 9.2.4 Vertical distribution within seams

The stratigraphic distribution of quartz and, to a lesser degree, kaolinite within seams is highly irregular (Figure 9.9). However, a feature common to many seams is quartz enrichment near seam contacts, as frequently noted in other deposits (Davis *et al.*, 1984; Gloe and Holdgate, 1991; Brockway *et al.*, 1991; Ward, 2002).

Within the Lochiel Deposit, H Seam the abundance of quartz typically decreases upward (paralleling macroscopic observations), although in thicker seam developments banding may occur, while kaolinite can either increase slightly up seam, or fluctuate in abundance (Figure 9.9). G Seam is characteristically low in quartz, except in the immediate vicinity of clastic interfaces and occasional thin sand-rich horizons. The latter represent distinct sediment pulses, and are generally located near the lateral margins of the seam. In contrast, the kaolinite profile commonly displays a slight upward increase (possibly related to variations in coal facies; see Section 9.2.5), although enrichment within the centre of the seam may also occur. While generally independent of quartz, elevated kaolinite levels are also possible near seam interfaces (Figure 9.9). In F Seam, high quartz is common near the seam floor where it is macroscopically visible as fine sand laminations.

The mineralogical profiles of seams in the Bowmans Deposit are relatively consistent throughout the sequence, especially with regard to the quartz component. In areas of thick coal development the typical pattern is one of increased quartz immediately near seam boundaries (especially within 0.1 to 0.5 m of the floor), with relatively low to very low quartz contents away from the contact (Figure 9.9). Within individual seams, clearly defined and correlatable gradients are absent, although thin horizons of significant quartz enrichment and locally developed gradients sometimes occur. Kaolinite likewise shows limited vertical variation, except for occasional local enrichment near seam boundaries.

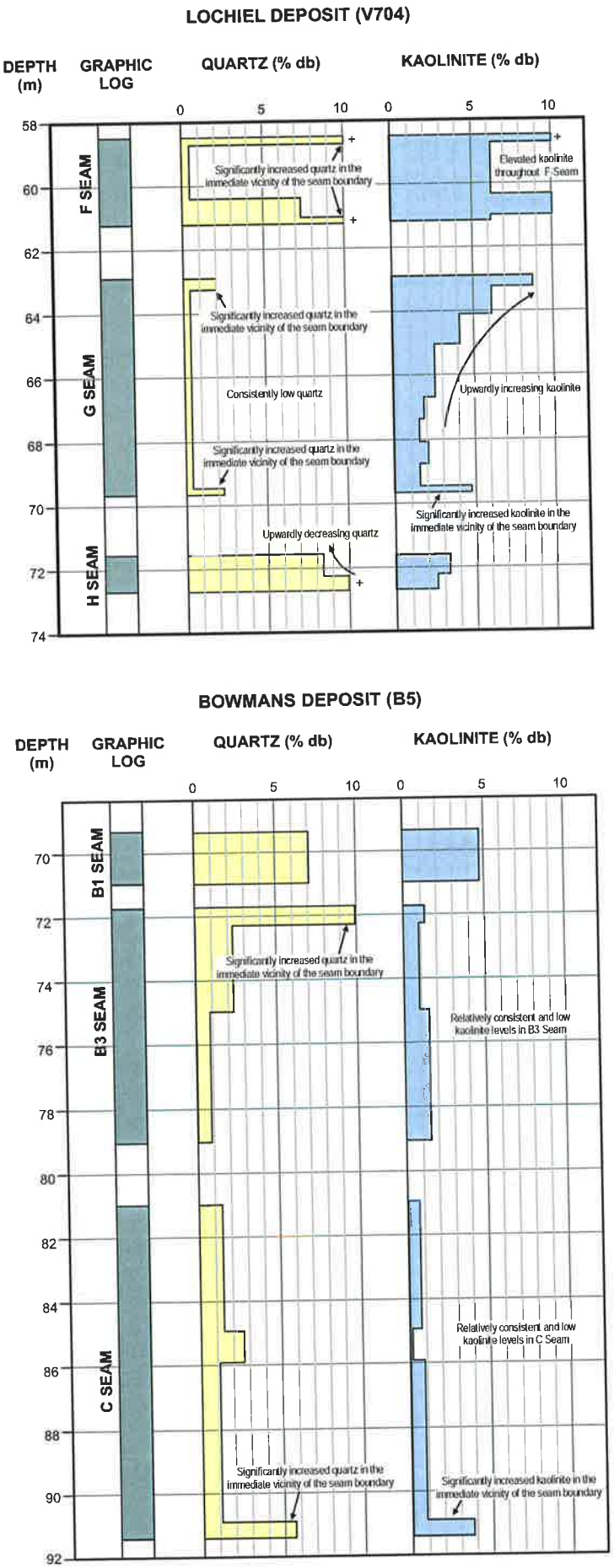



Figure 9.9 Vertical mineral distribution

In summary, the vertical distribution of mineral matter through the coal measures of both deposits appears strongly influenced by the proximity of seam boundaries, where quartz and, to some extent, kaolinite can be significantly enriched. Within seams more subtle trends occur, especially in kaolinite, and the two mineral profiles in question tend to be regionally inconsistent. Well-defined, consistent profiles are restricted to the H and G Seams at Lochiel where they highlight upwardly decreasing quartz and upwardly increasing kaolinite contents. Some in-seam fluctuations may be related to changes in coal facies.

### 9.2.5 Facies associations

Within both deposits, but especially at Lochiel, silicate mineral content varies systematically with facies (Table 9.3; Figures 9.10 and 9.11). Of the two major minerals, quartz provides the clearest differentiation, its average concentration being moderate (~3% by weight, dry coal basis) in facies I, low (~1%) in facies II, and very high (~11%) in facies III. Kaolinite is more evenly distributed between the primary coal types, with low to moderate concentrations (2-3%) in facies I and II and high levels (~6%) in facies III. Overall, facies I contains ~6% of these major silicate minerals (Q>K), facies II ~4% (K>Q), and facies III ~17% (Q>K).

Table 9.3 Average mineral abundances for each facies and deposit

| **Deposit / Mineral** | **Facies I** | | | | **Facies II** | | | **F III** | **Facies IV** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ia | Ib | Ic | Ave. | IIa | IIb | Ave | | IVa | IVb |
| LOCHIEL | | | | | | | | | | |
| Quartz (% db) * | 5.4 | 1.7 | 1.5 | **3.0** | 0.5 | 0.3 | **0.4** | **11.4** | 24.6 | 0.3 |
| Kaolinite (% db) * | 3.1 | 2.7 | 4.3 | **3.0** | 2.1 | 4.2 | **3.2** | **6.1** | 4.3 | 7.3 |
| Quartz/Kaolinite * + | 3.8 | 2.0 | 0.8 | **2.5** | 1.3 | 0.2 | **0.7** | **3.4** | 4.9 | 0.1 |
| | (1.7) | (0.6) | (0.4) | **(1.0)** | (0.2) | (0.1) | **(0.1)** | **(1.9)** | (5.7) | (0.04) |
| BOWMANS | | | | | | | | | | |
| Quartz (% db) * | 1.7 | 2.8 | i/s | **2.5** | 1.1 # | | | | | |
| Kaolinite (% db) * | 1.8 | 1.1 | i/s | **1.4** | 3.7 # | | | | | |
| Quartz/Kaolinite * + | 2.8 | 9.9 | i/s | **7.4** | 1.3 # | | | | | |
| | (0.9) | (2.5) | i/s | **(1.8)** | (0.3) # | | | | | |

Key: i/s Insufficient data for useful determination
# Based on average of sub-facies IIa-2 and IIa-3
* Values for mineral content and ratios represent facies averages, calculated using all individual samples (123 samples at Lochiel and 87 at Bowmans)
+ An additional ratio calculated from the average mineral in each facies is show in brackets

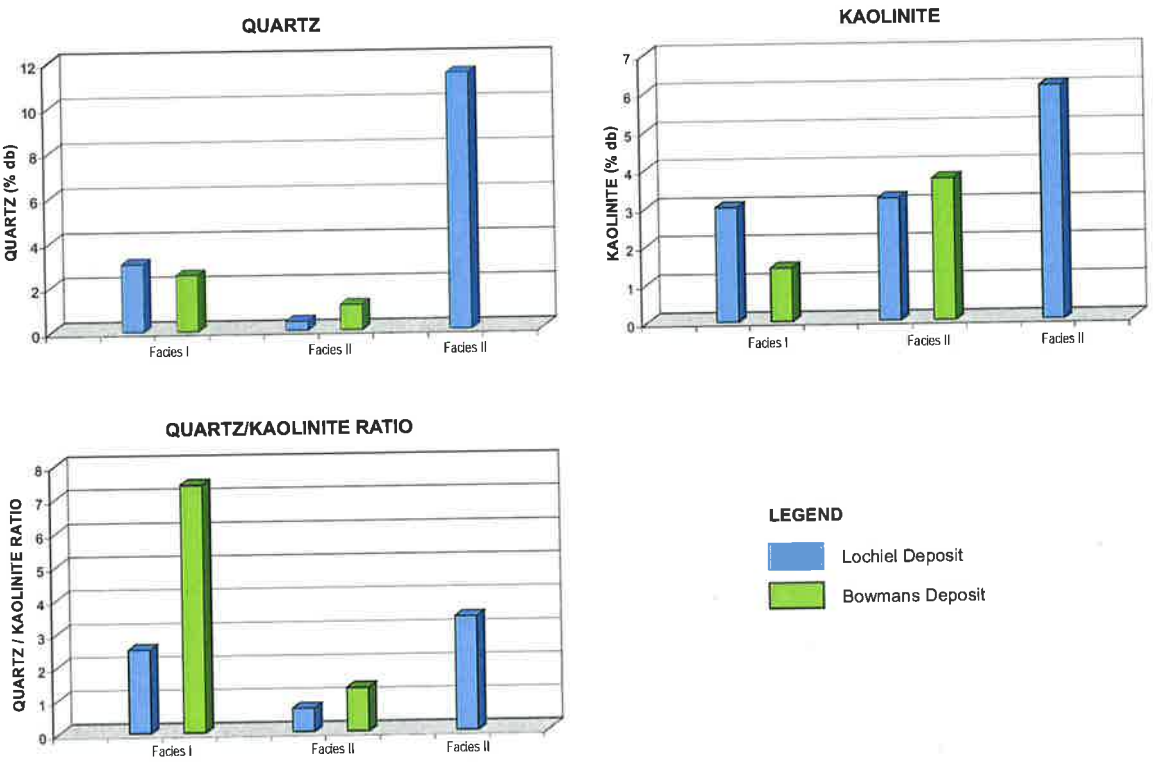



Figure 9.10 Mineral variations with facies

Some degree of mineralogical variation is also evident between sub-facies (Table 9.3), particularly those of facies I. Here, within facies Ia, quartz (macroscopically visible as either sand horizons or dispersed grains is commonly associated with large woody fragments and so the mineral content of the coal seam can vary considerably over short lateral intervals (Figure 9.12). Relationships between wood-rich coals and sand were noted by Kravitis and Crelling (1981) in Pennsylvanian coals of southern Illinois. Kaolinite levels are reasonably consistent across the facies I spectrum, unlike in facies II where those in sub-facies IIb are twice those in sub-facies IIa. While similar intra-facies trends are evident in both deposits, the degree of fluctuation between sub-facies is greatest at Lochiel, paralleling this deposit's increased facies diversity. Of the altered coals, sub-facies IVa is very rich in quartz, along with moderate kaolinite, while sub-facies IVb coals contain abundant kaolinite and very little quartz (Table 9.3).

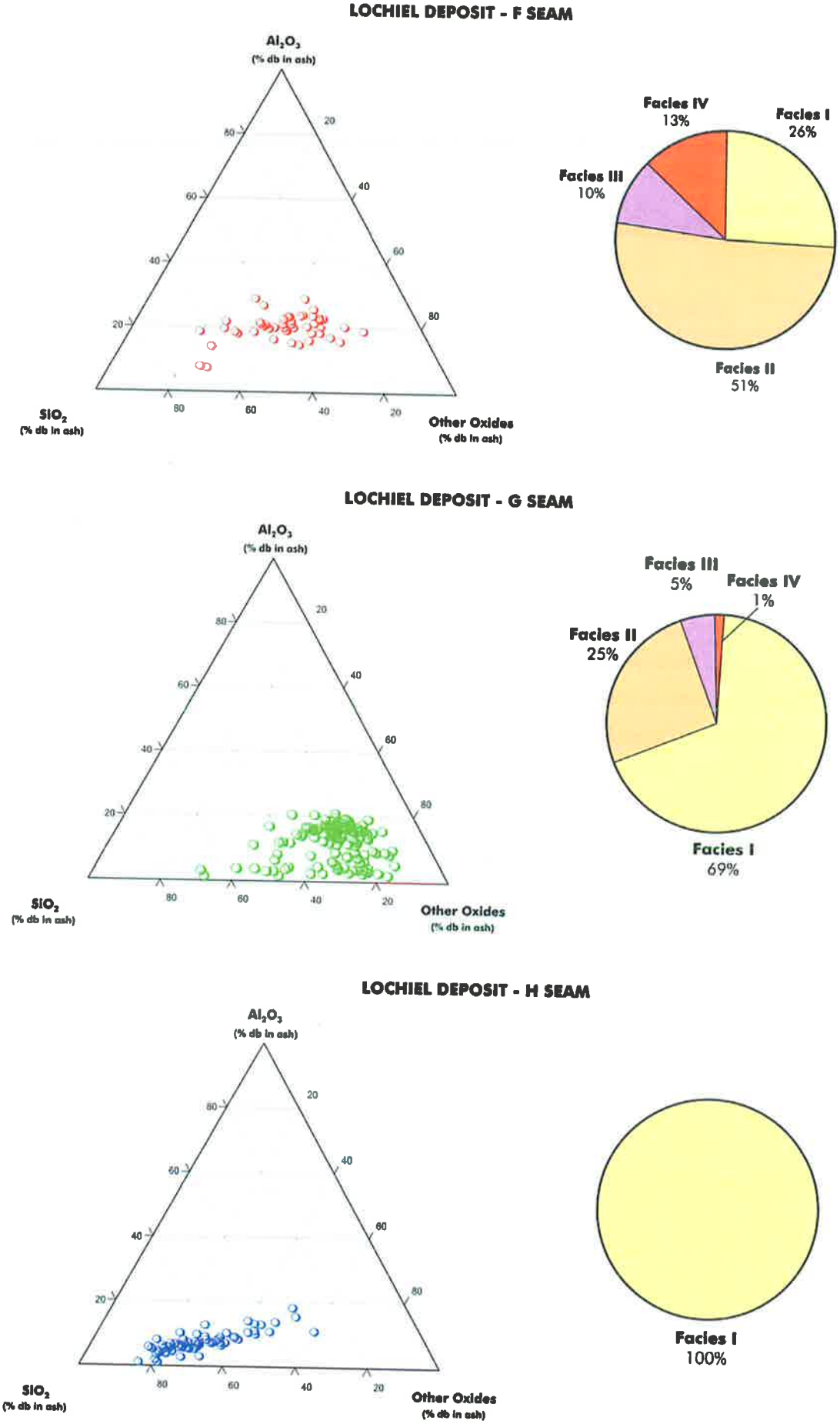



Figure 9.11 Facies to mineral relationships

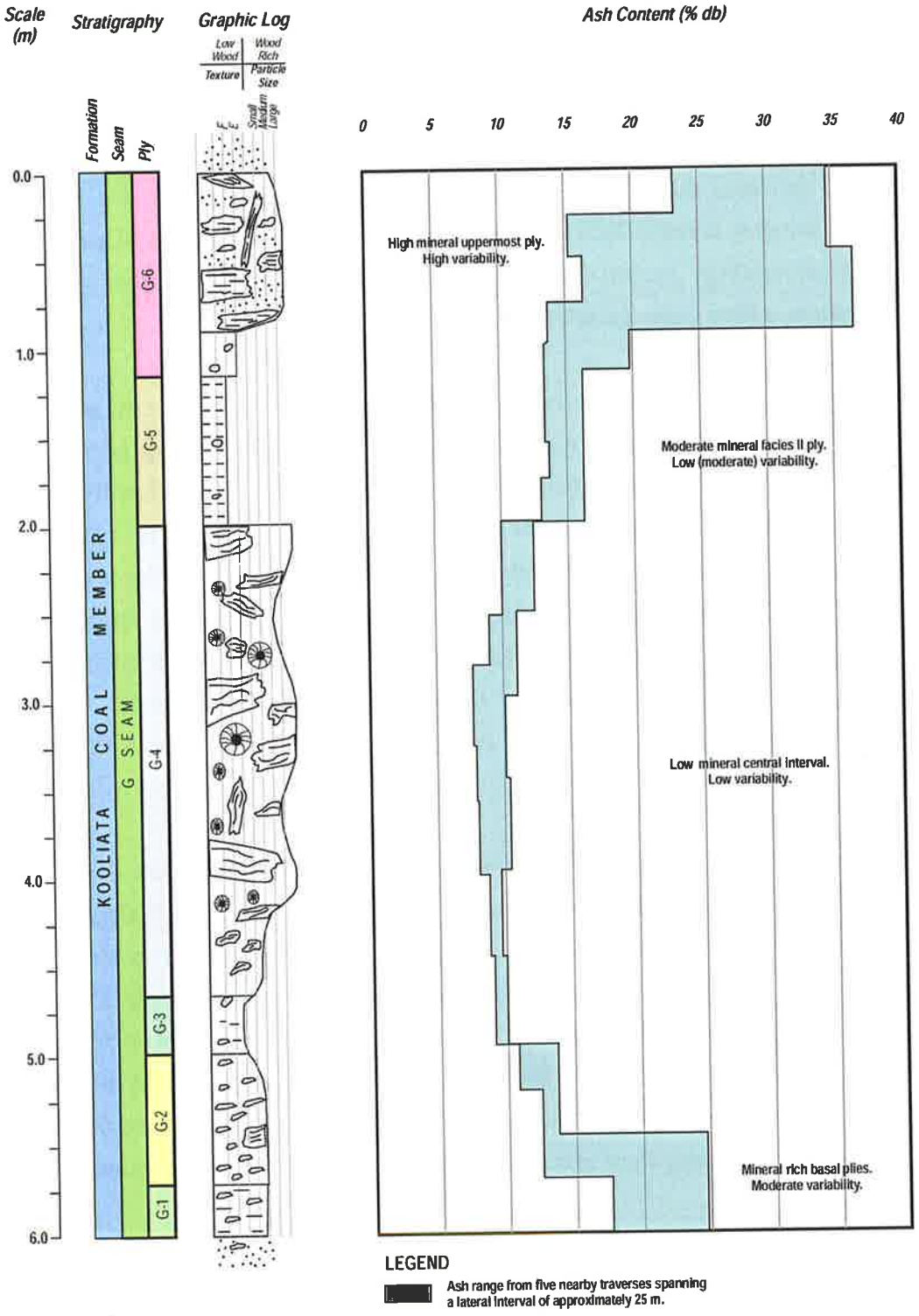



Figure 9.12 Lateral mineral variability

## 9.3 IMPLICATIONS OF QUARTZ AND KAOLINITE DISTRIBUTION FOR PALAEOENVIRONMENTAL EVALUATION

The mineral content of a Lochiel and Bowmans coals seam is determined by the interplay of several important factors. These include its location relative to the lateral margin of the original mire, (mineral matter is usually higher in proximal settings), the stage of seam development (mineral content increases near the roof and floor) and local palaeoecological environment (mineralogy varies with coal facies). However, the manner in which these factors interrelate differs between seams and deposits.

In general terms, quartz tends to increase dramatically near lateral and vertical seam margins where it is commonly associated with splitting and thinning, reflecting periodic overbank incursions, or local clastic influx adjacent to the swamp margin. Significantly, the principal criterion for coal definition (i.e. a cut-off based on 30% by weight ash on a dry coal basis), serves to mask this trend as the higher-mineral portion of the seam is progressively excluded in line with lateral facies change. Sites closer to seam depocentres appear sufficiently removed, or protected, from clastic deposition resulting in generally lower quartz contents and more gradual variations in its abundance. Distinct regional trends in quartz can also occur (e.g. H Seam at Lochiel) where a unidirectional source persisted throughout the coal-forming period.

Kaolinite distribution and its relationship to seam margins is more complex. Instances of both decreasing and increasing kaolinite content toward the seam depocentre were detected (i.e. parallel and antithetical to the quartz distribution, respectively), as well as a regional trends unrelated to quartz distribution and seam thickness. Furthermore, elements of these patterns can be represented in a single seam with sharp transitions between areas of high and low mineral abundance. The variability of the kaolinite distribution may reflect the interaction of detrital and authigenic formation processes, with the former possibly more dominant in the Lochiel Deposit where strong local gradients in the abundance of this clay mineral occur.

### 9.3.1 Regional setting

The dominance of quartz and kaolinite in the northern St. Vincent Basin coals is consistent with intense weathering of its bedrock (Stuart, 1969) under tropical conditions (Christophel, 1994; Rowett, 1997; Wust *et al.*, 2002). However, gross changes in coal mineralogy between deposits indicate some degree of regional variation in coal- forming conditions. Critical differences include increased kaolinite and, to a lesser extent, reduced quartz in the coals at Lochiel relative to those at Bowmans.

Strong kaolinite gradients unrelated to coal thickness and seam peripheries support the likelihood of mainly authigenic formation at Lochiel, whereas both authigenic and detrital processes are inferred to have operated at Bowmans, albeit to a significantly lesser degree. Regional factors that militate against the authigenesis of kaolinite at Bowmans are possibly associated with gross changes in swamp conditions. Black (1982) noted a kaolinite-dominated mineralogy in limnic coals, relative to a more diverse mineralogy in those from paralic settings. Increased marine influence on the Bowmans Deposit and the accompanying changes in pH, Eh and the microbial regime may thus help explain the generally lower kaolinite contents of its coals.

Increased quartz at Bowmans is possibly a reflection of its fluviatile environment that favoured the introduction of quartz-rich overbank sediments. In contrast, the generally lower levels of fluviatile activity at Lochiel (apart from the southern portion of the deposit during the accumulation of H Seam) promoted conditions more conducive to kaolinite formation. Local conditions with the peat forming mire have also contributed, to the interdeposit differential, leading to significantly more development of the kaolinite rich facies II at Lochiel.

Other factors capable of influencing mineralogy, such as the level of sediment filtering around swamp peripheries, the nature of the bedrock in the surrounding hinterland, the relative mix of mechanical and chemical weathering, and the prevailing climate are likely to have been broadly similar across the region.

### 9.3.2 Deposit-specific conditions

Lateral changes in the major mineral components and their relative abundances within seams facilitate more detailed evaluation of the peat-forming environments of the northern St. Vincent Basin and, in particular, the interaction between the contemporary clastic and organic sedimentary regimes.

#### 9.3.2.1 Lochiel Deposit

The distribution of silicate mineral matter in the coal measures of the Lochiel Deposit suggests a relatively static detrital source during the time its peat was accumulating. A feature common to all seams is their higher quartz levels in the south and southeast, suggesting runoff from exposed bedrock and/or periodic overbank input from fluvial and fan delta sedimentation in the region (as postulated by Kremor, 1992). These mineralogical inferences are also supported by lithotype evidence that shows sand enrichment near the southern margin. Elsewhere, increasing quartz towards seam margins is probably a reflection

of local detrital input from adjacent peripheral uplands, while in central settings peat accumulation appears to have been relatively free of adventitious mineral. The northern portion of the deposit is most conducive to kaolinite accumulation, especially in H and G Seams, indicating preferential development in areas most remote from major detrital input. This is most likely related to the chemistry of the peat, and the coincidence of potassium ions and silicate in solution and the conditions necessary for its precipitation.

Changes in coal mineralogy through the sequence parallel the variations noted in facies distribution (see Section 7.5.1) and support the inference of a broad evolution in peat-forming conditions involving an increasingly elevated water table. H Seam peats received siliciclastic input, although quartz levels progressively diminish up sequence, possibly reflecting the combination of reducing clastic sedimentation and a tendency toward ombrogenous accumulation. Low quartz concentrations in G Seam and, in particular, their gradual radial decrease toward the interior suggest the near absence of direct detrital input throughout most of the area, except for some short duration pulses in the south. Minor quartz present in central settings is possibly wind blown, or authigenic. Furthermore, the overall pattern is consistent with a mixture of topogenous, ombrogenous and subaquatic deposition (i.e. facies I and II accumulation), possibly in concert with sediment filtering by vegetation along the swamp periphery. A major change in environmental conditions appears to have occurred in F Seam, paralleling the change to a dominance of facies II over facies I accumulation, and is highlighted by significantly increased kaolinite levels and broadly sympathetic quartz and kaolinite distributions.

#### 9.3.2.2 Bowmans Deposit

In the Bowmans Deposit major regional mineralogical trends exist, but they differ from one seam to the next, suggesting a somewhat dynamic paludal environment and changing patterns of sedimentation in the region. Zones of high quartz occur in the north and northwest of C Seam (Figure 9.6); in the northwest, west and south of B3 Seam (Figure 9.7); and in the south of the very restricted B1 Seam (Figure 9.8). This pattern is consistent with fluvial activity in the north (and northwest) during the initial pulse of peat formation with the southern expanse of the mire largely protected from mineral incursion. During the accumulation of B3 Seam, more extensive fluvial activity is interpreted, with the north to northwesterly source maintained, while additional incursion occurred from the west and south, paralleling seam splitting. A significant change in conditions is evident in B1 Seam, with high detrital quartz contents and abrupt splitting toward the south suggesting the existence of a major east-west-oriented fluvial channel to the south of a dramatically contracted mire. A reduced thickness of peat along the northern periphery of the seam appears relatively free of detrital input. It is noteworthy that quartz levels are not elevated on the northeastern margin of the deposit where

it abuts exposed pre-Tertiary bedrock. Evidently only minor local runoff either occurred, or reached the mire from this topographic feature.

In contrast to the mineralogy of coals in the Lochiel Deposit, the mineralogy of the Bowmans seams is relatively consistent reflecting the subtle nature of facies change through the sequence. There is, however, a detectable change from the quartz-dominated topogenous/ombrogenous conditions with minor subaquatic deposition recorded in the C and B3 Seams to a higher mineral content, more kaolinitic B1 Seam, as the proportion of subaquatic facies II increases.

### 9.3.3 Local depositional environment

Distinct variations in mineral composition between facies highlight the importance of local swamp conditions in determining coal mineralogy (Figures 9.10 and 9.11). Although the mineral assemblages are not such as to precisely define local palaeoenvironments of the individual facies, their patterns of mineralogical variation are in all cases consistent with inferences developed from maceral and biomarker data, and hence do not necessitate modification of the interpreted local peat-forming environments. However, position within the peat swamp, particularly proximity to the margin, is important factor that can override local depositional influences.

Facies I coals exhibit considerable mineralogical variation. Sub-facies Ia (especially where macroscopic fibrous wood is the major component) may show a distinctive high-quartz mineralogy that is attributable to overbank flooding into proximal forest settings. This association also suggests a relationship between overbank activity and tissue preservation, whereby the periodic mineral input facilitates both a luxuriant vegetation and rapid burial. In other words, the allochthonous sediment performs the dual role of providing nutrients and limiting the duration of exposure of the plant detritus to aerobic conditions. A degree of hypautochthonous relocation of woody material during significant overbank events may also be indicated. Relatively high silica levels in coal are thought to be characteristic of forest swamps (Diessel and Smyth, 1995). Lower mineral contents elsewhere (i.e. removed from the swamp margins or areas susceptible to fluvial influence), and in sub-facies Ib and Ic coals, is indicative of generally low detrital input and a tendency toward ombrogenous conditions. Elevated authigenic kaolinite with relatively low quartz in sub-facies Ic is possibly a by-product of a high Eh in the peat.

Relative kaolinite enrichment combined with low quartz in facies II is consistent with peat accumulation in settings protected from, or distal to, high energy fluvial activity where the siliciclastic input is mostly clay (Readett and Quast, 1990), or which receive very little detrital mineral matter and the kaolinite forms principally by authigenic means. In such

environments relatively high kaolinite levels may occur by default, as suggested by Ward and Swaine (1995), simply because authigenic mineral-forming processes are ongoing and independent of the severely restricted detrital input. The elevated groundwater table postulated for facies II (and, in particular, sub-facies IIb) would have provided a suitable environment for either scenario. They certainly are consistent with the findings of Diessel and Smyth (1995) who identified low silica content as an indicator of reed marsh environments.

Abundant fine quartz with significant kaolinite in facies III is indicative of regular input of fine detrital mineral matter. The interpreted high-groundwater environment with a steady input of finely fragmented organic matter and a relatively low rate of organic accumulation is consistent with the observed mineralogical properties of this coal facies.

Both types of altered coal have high mineral contents. The high quartz level in sub-facies IVa is possibly a combination of relative enrichment (i.e. as the organic component is depleted during combustion) and post-depositional incorporation into the porous matrix from overlying sediment. In sub-facies IVb extensive kaolinite enrichment occurs independently of the primary facies type and parallels the high kaolinite levels in sub-facies Ic. Its formation possibly involves the subaerial chemical weathering of other detrital silicates (Ward and Swaine, 1995).

### 9.3.4 Other inferences

In the coal measures at both Lochiel and Bowmans, sharp transitions are common between regions of high and low mineral abundance, suggesting well-constrained loci of clastic inundation and, in some cases, distinct changes in swamp conditions. Similar features were noted by Kravitis and Crelling (1981), who suggested that flocculation of suspended material by acidic swamp waters can abruptly limit the extent of mineral enrichment. Furthermore, in both deposits, the thicker seams tend to contain the least quartz, suggesting that their precursor peat accumulated in areas isolated or protected from detrital influx, while the thinner and marginal peats were prone to intermittent overbank detrital input.

Other than in H Seam at Lochiel, consistent vertical intraseam gradients suggestive of either subtle increases, or decreases in detrital input during peat accumulation were not detected. This pattern indicates that once stable peat-forming conditions became established organic accumulation predominated and overbank sedimentation was largely excluded. One or more of the following factors may have applied: a passive phase of clastic sedimentation coincident with coal formation (as postulated by Michaelsen and Henderson, 2000), development of ombrogenous conditions (Mackay *et al.*, 1985; Anderson and Mackay, 1990) or filtering of sediment by vegetation around the periphery of peat swamps (Kremor, 1992).

Mineral variations, especially quartz enrichment, in the immediate vicinity of seam roof and floor boundaries are widespread throughout the seams of both coal sequences. Similar features have been noted elsewhere (Davis *et al.*, 1984; Gloe and Holdgate, 1991). These possibly reflect contemporaneous organic and inorganic sedimentation and/or mixing of peat and clastic sediment assisted by bioturbation (Ward, 2002). High mineral concentrations near the floor of a basal seam may also reflect initial sedimentation in low-lying depressions inhabited by herbaceous aquatics where rates of organic accumulation were low (Raymond *et al.*, 1987). Such a scenario is also consistent with the basal development of facies II (and in some cases facies III coals) within certain seams. Upper boundaries tend to reflect more rapid changes in depositional conditions (including erosional activity), under which mineral enrichment in the peat is less common.

## 9.4 SULPHUR

Sulphur levels are typically high in the Lochiel and Bowmans coals. The bulk of this sulphur is organic (i.e. chemically bound within the kerogen matrix of the coal). Inorganic sulphur is less abundant and present in sulphide minerals such as marcasite and pyrite that occur as discrete aggregates and thin discontinuous fracture infillings. Significant lateral variations in sulphur abundance have been documented within seams and vertical concentration gradients are evident.

### 9.4.1 Abundance and distribution

The average abundance of total sulphur in seams varies significantly between deposits, ranging from 4.7-5.4% at Bowmans to 2.4-3.4% at Lochiel (Table 9.4). Furthermore, both deposits exhibit a well-defined upwardly increasing sulphur gradient, occurring as inter-seam steps and, in places, gradual intra-seam gradients (Figure 9.13). Total sulphur abundance does not appear to be a factor in the extent of vertical gradient development.

Table 9.4 Total sulphur abundance (weight percent, dry coal basis) in the Lochiel and Bowmans Deposits

| | **Lochiel Deposit** | | | **Bowmans Deposit** | | |
|---|---|---|---|---|---|---|
| | F Seam | G Seam | H Seam | B1 Seam | B3 Seam | C Seam |
| Average | 3.4 | 2.9 | 2.4 | 5.4 | 5.1 | 4.7 |
| Range | 2.6 – 5.5 | 2.1 – 4.4 | 1.7 – 2.9 | 3.7 – 8.3 | 3.8 – 8.0 | 2.8 – 5.5 |

Note: Values are based on drill core analysis over the full vertical seam interval. Seam average values are weighted from sulphur grid models over the area of data availability.

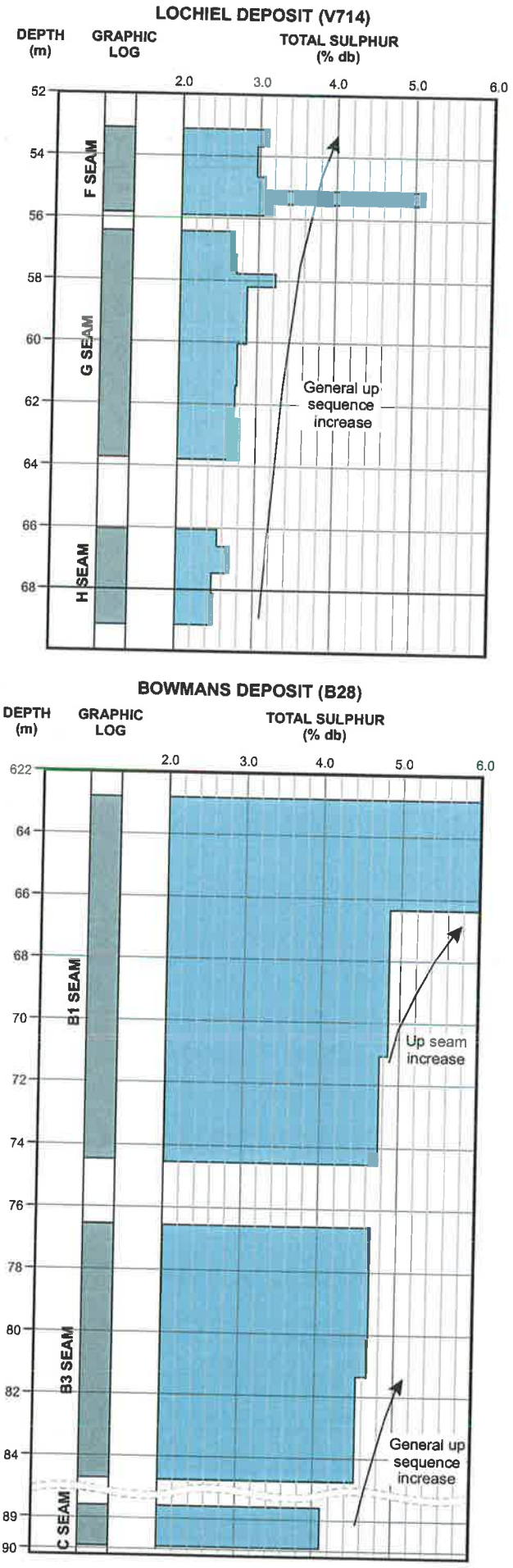



Figure 9.13 Vertical sulphur gradients

Significant lateral variations in sulphur abundance occur in all seams, as highlighted by the wide difference between maximum and minimum values, particularly at Bowmans (Table 9.4). At Lochiel these variations reflect regional gradients, whereby concentrations increase from south to north (and northeast) in H and F Seam and from west to east in G Seam. However, at Bowmans, the intra-seam range appears to primarily reflect local and somewhat erratic highs and lows, although in the B1 Seam a sharp easterly increase is evident.

Variations in total sulphur are essentially independent of coal facies, and are instead primarily controlled by the vertical position within the sequence and the location within seams (i.e. vertical and lateral concentration profiles). However, a slight increase is evident from facies I to II and III (Table 9.5), while the altered sub-facies IVa coal shows significantly enrichment in organic (and pyritic) sulphur.

Table 9.5 Variation of average total sulphur content (weight percent, dry coal basis) with facies and deposit

| Deposit | Facies 1 | | | | Facies II | | | F III | Facies IV | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ia | Ib | Ic | Ave. | IIa | IIb | Ave | | IVa | IVb |
| Lochiel | 2.7 | 2.8 | 2.5 | **2.7** | 3.1 | 2.9 | **3.0** | **3.3** | 5.6 | 2.9 |
| Bowmans | 4.6 | 4.5 | 4.6 | **4.6** | 4.9 | | **4.9** | | | |

Key: Shaded coal varieties do not occur in the Bowmans Deposit

### 9.4.2 Palaeoenvironmental implications

High sulphur contents and upwardly increasing gradients in both deposits are suggestive of widespread marine influence throughout the region following peat accumulation. The correlation between high sulphur and marine proximity and/or overlying marine sediments has been noted by several workers (Williams and Keith, 1963; Casagrande *et al.* 1978; Black, 1982; Westgate and Anderson, 1984, Cohen *et al.*, 1984; Kiss *et al.*, 1985; Holdgate *et al.*, 2000). Diffusion of sulphate-rich porewaters from overlying marine and marginal marine sediments of the Rogue Formation at Bowmans and the Tarella/Warrindi Silt at Lochiel, respectively, could account for this distribution. However, lateral sulphur gradients have little potential for direct palaeoenvironmental interpretation due to their post-depositional nature and sensitivity to the permeability of overlying sediments (as noted by Kravitis and Crelling, 1981).

Elevated sulphur in the Bowmans coals relative to those from Lochiel possibly reflects a combination of sedimentological and post-depositional factors. These include a more proximal marine setting during coal deposition, more prolonged exposure to marine waters, and better access of sulphate ions to the peat horizon via more permeable overlying sediments. Furthermore, these findings are consistent with sedimentological, palynological and facies investigations; and, in particular, the inference of an open, near-marine setting for

peat accumulation in the Bowmans Deposit, compared to a more restricted sub-basin setting in the Lochiel Deposit. Direct evidence for sulphur incorporation during peat accumulation (as noted by King *et al.*, 1983 and Holdgate *et al.*, 1995) was not detected, either from the sulphur abundance, or clastic sedimentology.

The relationship between local coal-forming environments and sulphur abundance is tentative. A slight increase in sulphur from facies I to III is consistent with the progressively elevated groundwater levels inferred for these facies, less oxic conditions and, in turn, greater potential for bacterial sulphate reduction. However, the occurrence of facies II and III coals also increases up sequence, paralleling upward sulphur gradients. Furthermore, the high sulphur levels in sub-facies IVa may reflect ready access to sulphate- rich waters at the uppermost seam roof and/or increased potential for sulphur absorption by this high-inertinite, carbon-rich coal. Enrichment of marcasite and pyrite, in fractured zones from Gippsland Basin brown coals has been reported by Ward and Swaine (1995).

## 9.5 SUMMARY

Quartz and kaolinite are the major silicates in the Lochiel and Bowmans coals, with the former mineral dominant in all but the F Seam at Lochiel. However, the quartz to kaolinite ratio is significantly higher at Bowmans where it is consistent with other data (e.g. sedimentology, coal petrology and biomarker) in highlighting marked palaeoenvironmental variations between the two deposits. Differences in swamp conditions and associated changes in pH, Eh and microbial conditions, together with higher levels of fluvial activity at Bowmans relative to Lochiel, are possibly key factors influencing the variable interdeposit mineralogy.

At any given level in the Lochiel coal measures, the contribution of quartz to the ash diminishes from the margins of the seam towards its depocentre(s). Quartz is most abundant in the south and southeast, suggesting a long-lasting detrital source in this region, although its influence diminished somewhat after the end H Seam deposition. Elsewhere, runoff from local proximal sources is postulated to have occurred. Kaolinite, in contrast, shows a well-developed south-to-north gradient in H and G Seams and is interpreted to be predominantly authigenic mineralisation. In F Seam, where kaolinite levels are greatest and they parallel quartz abundance, a combination of detrital and authigenic kaolinite formation is inferred. At Bowmans, quartz appears mainly detrital and typically shows a relationship with seam thickness. Its abundance is highest adjacent to zones of splitting and thinning, and declines toward the seam depocentre. The locus of quartz enrichment shifted with time. The initial detrital influx was from the northwest, followed by simultaneous inputs from the northwest and south. Finally, the dominant source of siliciclastic sediment lay to the south of the Bowmans mire. The distribution of kaolinite is variable, displaying no fixed relationship with

seam thickness and thus suggesting that it comprises both detrital and authigenic mineralisation.

The observed mineralogical variation with coal type indicates that facies II peats were favoured sites of kaolinite formation, while the other primary facies are quartz dominated, especially facies III. This distribution is consistent with a subaquatic mire setting for facies II, open water for facies III, and a forested woodland prone to occasional overbank incursion for facies I. Both deposits show an up-sequence drop in the ratio of quartz to kaolinite, paralleling the increased relative abundance of facies II coal. Interaction between contemporary organic and clastic sedimentation is restricted to the immediate proximity of the seam floor and roof, especially in locations well removed from the lateral seam margins and areas of seam splitting. Assorted mechanisms including ombrogenous conditions, vegetation sediment traps and, in some cases, reduced contemporaneous sedimentation may account for the observed mineral distribution.

High sulphur levels and upwardly increasing sulphur gradients in both deposits are indicative of marine influence and post-depositional sulphur incorporation. Higher levels at Bowmans could reflect a combination of a slightly more proximal marine setting, more prolonged inundation of the peat by sulphate-rich waters and better access of sulphate to the reactive peat.

# 10 SUMMARY AND IMPLICATIONS FOR THE PALAEOENVIRONMENTAL ASSESSMENT OF OTHER TERTIARY COALS

This chapter presents a synthesis of the various elements of the present comparative study (viz. macro- and micropetrography, stratigraphy, sedimentology, mineralogy and biomarker geochemistry) of the Tertiary coal successions in two adjacent depocentres within the northern St. Vincent Basin of South Australia. The findings and outcomes of this research are summarised in relation to the specific project objectives outlined in Chapter 1 and, ultimately, with respect to the overall aim of elucidating the hitherto poorly documented depositional environments of these pre-eminent South Australian brown coal resources.

## 10.1 COAL DEFINITION AND FACIES CLASSIFICATION

A set of criteria was developed specifically for the genetic classification of coals in the Lochiel and Bowmans Deposits, using their lithotype and maceral attributes. The lithotype characteristics chosen for this purpose were groundmass texture (including groundmass tissue concentration and fragment size) and wood content (including morphology and abundance). These features exhibit a wide variability and can generally readily differentiate coal types. Other macroscopic features employed for classification include colour, gelification, fracturing and mineral content, although these typically allowed only limited differentiation, or were particularly distinctive only for specific coal varieties. Micropetrographic criteria included maceral group composition, tissue preservation, gelification, liptinite assemblage and the degree of liptinite alteration. These maceral characteristics vary widely across the coal suite thereby facilitating development of assorted quantitative indices to assist coal definition.

Several relationships were discernable between the macroscopic and microscopic characteristics. The key lithotype parameters of texture and wood content are closely associated with tissue preservation, while colour correlates with both gross maceral composition and gelification. In addition, some physical attributes such as fracturing and hardness correlate with increased inertinite content. Integration of these data sets led to the definition of eight discrete coal types or facies, of which seven are recognisable at the lithotype and maceral levels, with the eighth detectable only from macroscopic appraisal. Each coal is considered to represent a genetically distinct member, and to reflect unique depositional conditions.

The eight coal types can be classified into three primary facies, with assorted sub-facies and one altered facies. Each primary facies is interpreted to be the product of a broad palaeoenvironmental setting, while sub-facies are thought to represent more subtle changes in either the precursor vegetation, or its level and type of biomechanical degradation.

Facies I coals are humic in nature and are distinguished by low gelification, a moderate to high content of terrestrial liptinites (mainly resinite and suberinite), minor groundmass tissue and very little inertinite. Detrovitrinite (especially attrinite) is dominant, along with lesser amounts of telovitrinite, mainly in the form of large discrete phytoclasts. Macroscopic characteristics include an earthy to weakly fibrous texture, a medium (to light) brown colouring and variable amounts, morphologies and sizes of woody fragments. Three sub-facies were defined, principally on the basis of their level of tissue preservation and liptinite content, although changes also occur in other properties like colour, texture, secondary liptinite abundance and inertinite content. Sub-facies Ia is distinguished by its macroscopic wood fragments, abundant large telovitrinite phytoclasts, and moderate levels of well-preserved liptinite within a detrital groundmass. Sub-facies Ib has attributes very similar to those of the groundmass in sub-facies Ia coal, having an earthy texture, low wood and telovitrinite contents and a moderate to high liptinite content. A very high liptinite content, poor tissue preservation, bituminitic groundmass and slightly elevated inertinite (especially funginite) together distinguish sub-facies Ic coals.

Facies II coals differ markedly from those of facies I. Macroscopically they are dark, poor in wood and rich in mainly dark platy tissue, while their key maceral characteristics include a moderate to high abundance of groundmass telovitrinite, a mixed assemblage of terrestrial and aquatic liptinite, and well-preserved tissue with a moderate to high degree of gelification. Detrovitrinite, especially densinite, is dominant; liptinite contents are moderate to low (with cutinite common); and inertinite (especially fusinite) is elevated significantly with respect to the other primary facies. Two sub-facies were recognised and differentiated to accommodate differences in liptinite composition, inertinite abundance and gelification. Sub-facies IIa coals are somewhat transitional to facies I, especially in their liptinite assemblage within which resinite and suberinite are prominent, while groundmass telovitrinite abundance and gelification are moderate and inertinite content is low. In contrast, the liptinite assemblage of sub-facies IIb comprises mostly fine cutinite (along with lower levels of resinite and suberinite), groundmass telovitrinite and gelification are high, and the fusinite content is significantly higher than in all other varieties.

Macroscopically facies III coals are very dark, soft, wood free, well gelified and commonly show a conchoidal fracture pattern. Their texture is usually earthy, with minor groundmass tissue, resulting in a homogenous appearance. Although detrovitrinite dominated, these coals show sapropelic features, among them high to very high gelification (i.e. mostly desmocollinite and densinite), and a relatively uniform phytoclast size. Telovitrinite levels

are low and restricted to small and medium phytoclasts. Liptinite abundance is low to moderate, with both aquatic alginite and secondary fluorinite being present. Inertinite is low, detrital mineral matter is elevated with respect to other facies and microstratification may occur.

Facies IV coals have distinctive physical and, in some cases, maceral features that allow two sub-facies to be defined. Sub-facies IVa coals are rich in inertinite (mostly macrinite), although its abundance varies widely. Macroscopically, they are highly fractured where occurring in discrete horizons, but also exist as nodular particles within a vitrinite-dominated groundmass. Sub-facies IVb coals are recognised by their soft and friable consistency, somewhat mottled colouration and distinctly fractured appearance. Maceral properties are essentially those of the original coal, although a slight reduction in gelification, enrichment of liptinite and increased pitting of telovitrinite phytoclasts may occur.

## 10.2 PEAT-FORMING PALAEOENVIRONMENTS AND THE ORIGIN OF FACIES

The facies model proposed for the northern St. Vincent Basin coals (Figure 6.11) highlights the critical influence of groundwater level. Distinctly different settings are inferred for the primary coal facies including forest swamp, aquatic marsh and open water environments. Associated with the changes in palaeoenvironmental setting are major variations in the nature of the source material and its biomechanical degradation. Facies IV coals are interpreted as the alteration products of primary varieties.

### *Facies I*

A forest swamp environment in which peat accumulated from predominantly autochthonous vegetation is interpreted for facies I. Groundwater conditions may have ranged from topogenous permanent and intermittently inundated settings, to ultimately ombrogenous environments. The dominance of facies I coals, their occurrence in each seam and their formation of the thickest plies, suggests such conditions were both common and sustainable. Their moderate quartz and low kaolinite contents are consistent with a setting susceptible to occasional overbank incursion.

That facies I accumulated in forested settings is supported by its high levels of both angiosperm and gymnosperm biomarkers, of which the latter are largely restricted to this facies, and the presence of abundant woody fragments. Organic geochemical and palaeobotanical evidence suggests a mixed angiosperm-gymnosperm forest, with the former plant species forming the understory. Among the gymnosperms were members of the

*Podocarpaceae* and *Araucariaceae* families, while the most common angiosperm taxa were fossil *Myrtaceae* and *Proteaceae*.

Within this forested setting a number of sub-environments developed in response to subtle changes in local groundwater level, resulting in variable Eh regimes that in turn controlled the nature and extent of the degradation of the plant detritus. The formation of three sub-facies from similar woody vegetation is interpreted within the same overall facies I environment. Sub-facies Ia coals are those richest in woody constituents with a high degree of tissue preservation. A highly productive forest mire ensured a continuous supply of autochthonous plant detritus, with changes in the nature of the woody component possibly reflecting slight variations in local conditions. The infrequent presence of detrital quartz indicates a degree of overbank incursion; and its greater development near seam margins suggests the preference of this sub-facies for nutrient-rich, proximal channel settings. Sub-facies Ib and Ic appear to reflect somewhat more intense biomechanical degradation than that in sub-facies Ia, consistent with more prolonged subaerial exposure, possibly associated with ombrogenous conditions, fluctuating groundwater levels, or climate change. In sub-facies Ic intense aerobic bacterial and fungal activity is inferred, whereby only the most resistant constituents survived.

***Facies II***

Facies II coals are interpreted to be the products of peat accumulation under wet, elevated groundwater conditions that were sufficient to impede the growth of large terrestrial flora. Their organic input is likely to have been restricted to the soft tissue of herbaceous plants and marsh vegetation, as indicated by their low levels of terrestrial biomarkers (especially gymnosperm-sourced compounds) and sparsity of wood fragments. However, the lower ratio of gymnosperm to angiosperm biomarkers (relative to facies I) may simply reflect the persistence of smaller angiosperms in the wetter environment. Low mineral contents and very low quartz levels also support a subaquatic environment, with limited overbank influx of detrital quartz and conditions conducive to authigenic kaolinite formation.

Facies II coals are thinner and less abundant than the facies I varieties, but have greater laterally consistency. In addition, although regionally extensive, they are products of a less common and less productive mire than that of facies I. Most facies II constituent macerals appear to be autochthonous. Fusinite generated from forest fires, probably outside the swamp limits, is a notable exception.

Subtle variations in source input are inferred for the sub-facies varieties in line with compositional differences. A transitional setting between terrestrial and subaquatic environments (i.e. possibly in the immediate proximity of terrestrial forests) and extensive reed dominated mires well removed from terrestrial forests, are interpreted for sub-facies IIa

and sub-facies IIb, respectively. An uncommon variation of the former may occur where fine mobile constituents (i.e. hypautochthonous material) are redistributed from immediately surrounding terrestrial settings.

### *Facies III*

An open-water aquatic environment in which plant growth was limited and the organic input mainly fine allochthonous material is interpreted for the facies III coals. Such a setting would account for their advanced gelification, uniformly fine groundmass, low tissue content and aquatic liptinite assemblage. Facies III coals are the highest in mineral and most siliceous of the local varieties and contain the lowest levels of terrestrial biomarkers, especially gymnosperm-derived compounds, consistent with their accumulation as mineral-rich, organic muds in a treeless setting. Angiosperm biomarker levels, while low, are broadly similar to those in facies II coals, indicating allochthonous inputs from adjacent water-tolerant species.

Facies III coals are restricted to particular stages of seam development occurring either at the onset, or near the cessation, of peat accumulation. Lateral continuity is less consistent that in facies I and II coals. In places their horizons are discontinuous and thicken locally, especially in the basal portions of seams. Their contacts with other coal varieties and clastic sediment are typically gradational, with the latter generally represented by highly carbonaceous silts. Terrestrialisation of lacustrine environments (basal seam setting) and drowning of the peat by rising groundwater (upper seam position), are the interpreted sites of facies III occurrence. The limited development of facies III coals suggests an uncommon paludal environment in which the rates of peat accumulation were unusually low.

### *Facies IV*

Facies IV coals are products of the physical and chemical modification of the primary peats (viz. facies I to III). They are relatively uncommon and recognised only in parts of the Lochiel Deposit.

Distinctive maceral characteristics shown by sub-facies IVa coals such as high, but variable inertinite contents, oxidation of the gelified groundmass and partial liptinite removal are indicative of peat exposure and combustion. The occurrence of these coals in thin, highly irregular bands displaying significant vertical fluctuations is also consistent with such an origin. In some instances, sub-facies IVa coals are overlain by lacustrine sediments, suggesting extensive peat combustion that led to the development of local topographic lows. Reworking of partly combusted debris and its incorporation into fresh peat also occurred, although the precise location of the source material and the nature of its redistribution are

unclear. Sub-facies IVa formation correlates with periods of increased groundwater fluctuation, with preferred development in the upper portions of seams. The limited extent of these coals suggests that such conditions were relatively uncommon, although they may have developed on multiple occasions during peat formation.

Weathering of peat during periods of hiatus, prior to the deposition of overlying clastic sediments, gave rise to sub-facies IVb coal. Modification of the physical properties of the exposed peat resulted in a soft friable coal with a highly elevated kaolinite content and locally enriched in liptinite. The location of this coal type in the upper portion of seams with a transitional boundary to the underlying primary coal, is also consistent with a weathering-related mechanism. These coals are relatively uncommon and generally restricted to the upper portion of the coal zone at Lochiel, suggesting their origin generally post-dated peat accumulation.

## 10.3 EVOLUTIONARY PATTERNS IN LOCAL PALAEOENVIRONMENTS

### *Lochiel Deposit*

The initial phase of peat accumulation at Lochiel (i.e. Seam H) involved mainly autochthonous deposition in a wet terrestrial forest setting and resulted exclusively in facies I coal (Figure 7.13). In the south overbank incursions were widespread, resulting in significant enrichment of the peat in detrital quartz that progressively diminishes up sequence, and possibly also the introduction of some large woody fragments. Occasional periods of hiatus and pronounced aerobic bacterial and fungal degradation occurred, suggesting episodic groundwater fluctuation and/or periodic development of ombrogenous conditions.

G Seam is dominated by facies I, but contains significant amounts of facies II, some facies III and traces of facies IV coal. Fluctuating local palaeoenvironments are therefore inferred and overall the seam shows a tendency for increased frequency of ombrogenous/subaerial conditions up sequence. Peat accumulation commenced under subaquatic conditions in isolated and irregular topographic lows (Figure 7.13) which, following their progressive infill, became populated by water-tolerant swamp flora. Several groundwater fluctuations occurred during accumulation of the remainder of G Seam. These were of sufficient magnitude to cause widespread modification of the peat-forming vegetation that variously grew in terrestrial to partially ombrogenous forest swamp and treeless subaquatic settings. Debris from peat fires was introduced on occasions during the former stages, while allochthonous fusinite is common in the later subaquatic phases. The upper ply of G Seam accumulated in a forest swamp, although extensive biodegradation of plant tissue in the central areas of the deposit possibly reflects prolonged ombrogenous conditions and diminishing subsidence. More peripheral settings are marked by better tissue preservation and quartz enrichment. To

the south, local peat combustion occurred when lowering to the water table led to its exposure and desiccation. Clastic sediment is rare throughout most of G Seam and restricted to the seam peripheries.

F Seam comprises mostly facies II coal. It represents peat accumulation in settings that were for the most part submerged by an elevated water table, although a range of other transient environments occurred. Accumulation commenced in a forest setting prone to occasional, albeit progressively diminishing overbank influence, and was rapidly replaced by prolonged and generally stable subaquatic conditions (Figure 7.13). Variable groundwater regimes toward the end of F Seam accumulation included a brief reversal to terrestrial conditions, followed by semi-aquatic and open water phases and, finally, a substantial lowering of the water table that led to the exposure and partial combustion of the peat. Rebound of the water table and the ensuing lacustrine siliciclastic sedimentation terminated coal formation in the region.

Where changes occur within seams they tend to be laterally extensive, except for the immediate vicinity of seam margins where splitting, more variable facies occurrence and siliciclastic input may occur. The widespread presence of allochthonous fusinite in subaquatic coals suggests proximal drier forest settings and extensive fires. The latter were possibly a feature of the hinterland throughout much of the peat accumulation period.

A distinct evolutionary pattern is evident over the three-seam Lochiel sequence, whereby differing conditions prevailed during each successive phase of coal accumulation. Terrestrial forest conditions (leading to facies I accumulation) with a significant but diminishing clastic input during H Seam, evolved into the alternating terrestrial and semi-aquatic environments of G Seam (comprising mostly facies I and II coals) and finally into semi-aquatic to open water conditions during F Seam (predominantly facies II, grading into facies III). This pattern also parallels a gross change in clastic sedimentation, from fluvial preceding H Seam to lacustrine overlying F Seam.

The tendency towards progressively wetter conditions through the coal sequence is interrupted by several periods of relative stability. This pattern is highlighted by the facies distribution within G Seam which, although showing a broad trend from isolated open water settings to topogenous forest swamp and ultimately ombrogenous conditions, is punctuated by episodes of elevated water table conditions. Furthermore, the presence of sub-facies Ic coal at assorted intraseam positions reflects ombrogenous and/or static conditions that were in fact a common phenomenon during peat accumulation. The overall upward trend of increasing facies II and III abundance, relative to facies I, is indicative of greater facies differentiation over time caused by larger shifts of the water table that became more frequent in the latter stages of peat formation.

Tectonic activity involving movement along the Ardrossan Fault and, to a lesser extent, the Whitwarta Fault would have exerted a strong influence over groundwater conditions within the Lochiel sub-basin (Figure 1.1). Episodic syndepositional fault movement is thus the likely driving mechanism of groundwater fluctuation and, ultimately, facies banding. Activity along these structures appears to have increased over time leading to greater coal differentiation and accelerated subsidence, which ultimately exceeds peat accumulation. Climatic and eustatic change may have been secondary factors, although direct evidence for their impact is not available from the current study.

***Bowmans Deposit***

The peat that became C Seam accumulated in forest swamps, although the initial phase followed lacustrine sedimentation and appears to have occurred in a semi-aquatic environment (Figure 7.14). Relatively rapid terrestrialisation led to the establishment of low-lying swamps suitable for larger forest vegetation. Once established, such conditions persisted resulting in a thick development of facies I throughout the seam, with only slight changes evident in coal characteristics and local palaeoenvironmental conditions.

The initial accumulation of peat in B3 Seam occurred under somewhat atypical subaquatic conditions in that its organic input was largely allochthonous. Low-energy mobilisation and relocation of leaf litter and other fine tissue from a proximal forest source into a semi-aquatic, largely unvegetated setting is envisaged. However, these conditions were of only limited duration and were succeeded by a forest swamp in which a thick peat accumulated (Figure 7.14). The relatively uniform characteristics of the resulting coal, reflect a stable relationship between the peat and groundwater surfaces.

The deposition of B1 Seam peat commenced under semi-aquatic conditions, which evolved rapidly into a forest swamp. Although persisting for some time with only slight variation, these conditions, unlike those within underlying seams, were modified by a rapidly rising water table. A shallow standing body of water devoid of forest taxa is envisaged, in which allochthonous terrestrial plant litter and the remains of semi-aquatic vegetation accumulated. The upper part of B1 Seam reflects a return to more typical, forest swamp conditions. Extensive peat accumulation at Bowmans was terminated by channel avulsion and partial erosion of the upper peat surface.

In marked contrast to the Lochiel Deposit, clear evolutionary trends are not apparent through the coal succession at Bowmans. A relatively consistent arrangement of facies occurs in all three seams. For each seam, peat accumulation commenced under subaquatic conditions, leading to thin facies II intervals, although the precise characteristics of their coals are somewhat variable. Subsequently, extensive swamps hosting water-tolerant forest vegetation

developed, resulting in thick facies I intervals. Once established, these environments remained stable, except that of the uppermost seam. An unusually high water table is indicated for much of B1 Seam, possibly caused by a eustatic rise in combination with local sedimentological conditions.

Within the thick facies I intervals of the Bowmans succession, variations in coal characteristics are quite subtle and their occurrence is neither systematic nor correlatable. Their presence may reflect the development of localised sub-environments in the forest swamp setting, each marked by slightly different source material and style of preservation. Evidence also exists for periods of hiatus and occasional phases of more intense aerobic activity.

The consistency of the facies arrangement within the seams of the Bowmans Deposit corroborates other evidence (viz. limited facies diversity and thick ply development) in suggesting a generally stable groundwater regime. Furthermore, the influence of contemporaneous tectonic and eustatic processes on the coal facies of this deposit was minimal. The intra-seam distribution of facies indicates that the initial semi-aquatic conditions were of limited duration, and gave way to a persistent forest swamp. Autosedimentological modification of the local environment is sufficient to account for this change.

***Overview***

Secular changes in coal characteristics are apparent within most seams and more broadly throughout the coal sequence, especially in the Lochiel Deposit. Progressive terrestrialisation and reduced accommodation space in the mire where conditions evolved from semi-aquatic to topogenous forest swamp and, in some cases, ombrogenous conditions is evident in both deposits. While less common, converse trends of paludification, increasing accommodation and rising groundwater that accompany the change from terrestrial to aquatic environments, are also apparent in the Lochiel Deposit. However, in both instances and particularly at Lochiel, facies sequences are typically punctuated by fluctuations and temporary reversals in groundwater conditions. Rapid changes in water level are typical of facies I/II transitions. Furthermore, peat accumulation may be episodic and separated by periods of hiatus during which increased biomechanical degradation (sub-facies Ib and Ic), combustion, (sub-facies IVa) and weathering (sub-facies IVb) occur.

The distribution of facies within seams is variable, particularly for the less common varieties which reflect more extreme depositional conditions. Open-water facies III environments are the least extensive, hosting either the initial or final phases of peat accumulation in a given seam. Altered facies IV coals are typically (but not exclusively) developed near the seam

roof. Terrestrial facies I coals occur at most stages of seam development, but are less common in basal locations.

Development of subaquatic facies II environments was extensive throughout the peat-forming area of both sub-basins, with limited contemporary accumulation of other facies during these phases. However, the forest settings of facies I were more complex, comprising an array of laterally contiguous sub-environments, each with its own elevation relative to the local water table and palaeobotanical assemblage.

In the Lochiel Deposit the trend of progressively rising groundwater levels and rapid changes in coal type up section appear related to contemporaneous tectonic activity. The Bowmans Deposit appears to have been less affected by local tectonism. Instead, its peat accumulated in more stable mire settings where autosedimentological processes were responsible for a rapid evolution from early semiaquatic to persistent forest swamp conditions.

## 10.4 COMPARISON OF MIRE ENVIRONMENTS IN THE LOCHIEL AND BOWMANS SUB-BASINS

Coals of the adjacent Lochiel and Bowmans Deposits occur within similar sedimentary sequences and possibly constitute members of a common diachronous Early Tertiary succession (Figures 4.2 to 4.4). However, their attributes differ markedly with respect to seam geometry, facies diversity and arrangement, coal distribution, biomarker distribution and mineral characteristics.

Seam geometry at Bowmans is characterised by rapid splitting away from depocentres and significant changes in attributes over short lateral distances, with termination achieved principally by splitting. The regional distribution of coal is also variable, seams contracting significantly in area up sequence and becoming progressively restricted to the north of the sub-basin. In contrast, the seams of the Lochiel Deposit have a regular, lensoidal form and relatively static depocentres. Splitting is limited to the immediate vicinity of the outer seam margins and seam termination occurs by a combination of lateral facies change (into sandy coal) and splitting.

Low facies diversity is characteristic of the Bowmans Deposit, where only four of the eight coals types occur and varieties reflecting more extreme conditions (i.e. facies III and IV) are absent. Furthermore, maceral characteristics such as gelification, liptinite content and composition, and inertinite content exhibit only limited variability. In the Lochiel Deposit, all the coal types with a wide range in maceral attributes are present and facies II, in particular, is far more prominent. The spatial characteristics of coal in the two deposits are also distinctly different. Well banded, distinctive and laterally extensive plies are a feature of the Lochiel

Deposit. Here ply boundaries commonly coincide with changes in facies, a number of distinctive marker horizons exist, and ply thickness ranges from 0.1 to 2 m (average ~1 m). In contrast, the plies of the Bowmans Deposit are typically thick (0.2- 6.5 m, average ~2 m), relatively indistinct and display only limited banding. Here their definition is commonly based on sub-facies boundaries. At Lochiel there is a distinct upward progression from terrestrial to subaquatic facies, whereas at Bowmans forest facies dominate each seam.

The same classes of terpenoid biomarkers occur in each deposit, although significant differences exist in the specific compounds present and their relative abundance. Higher plant-derived sesquiterpenoids, diterpenoids and triterpenoids are slightly more abundant at Bowmans, while bacterial hopanoids are enriched at Lochiel. The most prominent inter-deposit variation relates to the abundance of 22R-17$\alpha$(H),21$\beta$(H)-homohopane (one of two significant bacterial markers) in facies I, which is approximately four times higher in the Lochiel Deposit, possibly reflecting higher levels of *in situ* aerobic microbial activity. The abundance of representative angiosperm and gymnosperm terpenoids relative to the aforementioned bacterial marker differentiates six biomarker associations that correspond to petrographically defined coal facies. Mineralogical differences also exist between the two deposits, with the Bowmans coals being considerably richer in detrital quartz than those at Lochiel. Here an up-sequence evolution from quartz to kaolinite-dominated mineralogies parallels the increasing occurrence of facies II, while at Bowmans conditions appear to have been unfavourable for authigenic kaolinite formation.

Marine indicators such as marine dinoflagellates and total sulphur are greatest at Bowmans, although both deposits have upwardly increasing sulphur gradients. Marine and marginal marine sediments succeed the Bowmans coal-bearing sequence with apparent conformity, while at Lochiel a hiatus separates the upper coal from overlying marginal marine to estuarine sediments.

An open, fluviatile, paralic setting with a relatively stable groundwater regime (possibly hydraulically connected to the sea), either set behind coastal barriers or sufficiently landward to prevent marine incursion, is interpreted for the Bowmans Deposit. Here peat accumulated in inter-channel settings, leading to thick and extensive but in places highly variable seam geometries. The dynamic sedimentary conditions and interaction between organic and clastic sedimentation are especially evident in the upper seams.

A strong autosedimentological influence on seam distribution, characteristics and facies development is interpreted for the Bowmans coals. Gradational boundaries and an absence of distinct and widespread facies changes within their seams suggest they were unaffected by contemporaneous movement along local faults, although earlier uplift of the adjacent hinterland did determine the optimum site of peat formation. Eustatically driven elevation of

the water table was responsible for the eventual migration and restriction of coal accumulation to the north of the sub-basin.

Coal accumulation at Lochiel occurred within a restricted sub-basin hosting southerly prograding fan delta and fluviatile sedimentation. This palaeogeographic setting was prone to significant and repeated groundwater fluctuations. A variety of peat-forming environments (ranging from ombrogenous through wet forest and semi-aquatic to open-water lacustrine) resulted in numerous clearly differentiated coal types comprising relatively thin plies with sharp boundaries and well developed banding. Fires were widespread and frequent in surrounding drier forest settings. The mires remained relatively free of siliciclastic mineral matter, except for periodic pulses of fluvial sedimentation and local peripheral input.

Early Tertiary tectonic movement is thought to have been a major control on palaeoenvironmental conditions in the Lochiel Deposit (Figure 4.2), leading to progressively increasing subsidence, diverse well-banded coals and a tendency toward semi-aquatic varieties over time. However, other factors such as climatic and seasonal variations and autosedimentological mechanisms, including terrestrialisation at the seam base and development of ombrogenous conditions within seams, may also have had an impact on the intra-seam characteristics of the peat.

While differing local palaeoenvironments are interpreted for the Lochiel and Bowmans sub-basins, the relatively consistent ratio of angiosperm to gymnosperm biomarkers in their coals suggests that a mixed forest persisted throughout the region, as also indicated by previous palaeobotanical investigations. While topogenous and ombrogenous conditions appear to have developed in both deposits, the resulting coals are predominantly low-ash humic varieties. Their high sulphur contents (particularly at Bowmans) reflect their paralic settings.

## 10.5 IMPLICATIONS FOR FUTURE STUDIES OF BROWN COALS

Our understanding of Tertiary coal-forming palaeoenvironments has been advanced in a number of ways by the current study. In particular, the factors influencing coal properties have been identified and their variation in response to local and regional geological stimuli investigated. Furthermore, a genetic coal classification has been developed and biomarker analysis and coal mineralogy integrated into palaeoenvironmental studies.

Two nearby deposits of Middle Eocene to Early Oligocene age formed within transgressive system tract sequences during the initial phase of basin infill and yet they show widely varying coal properties. The current research highlights the necessity for careful evaluation of local tectonic and sedimentary conditions and, in particular, their effect on groundwater conditions and suggests that caution is necessary when inferring coal characteristics from

their gross sedimentary setting. In particular, the effect of local conditions and the manner in which these may overprint regional coal characteristics is illuminated.

Inter-relationships exist between many macropetrographic and micropetrographic coal properties and coal differentiation can be optimised when they are applied in a fully integrated manner. Genetically related criteria for facies differentiation are ideally suited to the task of palaeoenvironmental reconstruction. In particular, the tools for coal evaluation and facies differentiation developed during the present research, rather than being specific to the Lochiel and Bowmans Deposits, have the potential for widespread utilisation outside the study area.

This study has demonstrated that a wide variety of local peat-forming environments existed in the northern St. Vincent Basin during the Tertiary, with rapid changes in coal type occurring in response to local geological conditions. While the importance of the nature and consistency of groundwater conditions was highlighted through their influence over both the nature of the plant detritus and the duration of its exposure to aerobic decay, the complex interaction of many interrelated factors was also apparent.

These Tertiary coals exhibit well-defined evolutionary changes in coal characteristics through both individual seams and the coal sequence, reflecting the progressive rise or fall of the local water table. However, this pattern may be punctuated by rapid reversals and increasing differentiation up sequence. Alternatively, relatively stable characteristics may become established following initial terrestrialisation of the mire. These patterns highlight the importance of local groundwater conditions, in conjunction with key controlling mechanisms such as local tectonism, eustatic influence and autosedimentological modification.

Detailed evaluation of brown coal biomarkers within facies and across deposits has revealed the highly variable nature of particular compound classes including sesquiterpenoids, diterpenoids, and des-A triterpenoids. While some changes relate to coal type, others occur independently of facies, thereby limiting their use in palaeoenvironmental analysis, particularly where only a few widely spaced samples are available. High levels of A-ring-contracted triterpenoids were detected in the Lochiel and Bowmans Deposits, and it appears that under certain conditions their formation and preservation can be significant in brown coals. However, a good correlation exists between angiosperm and gymnosperm-sourced biomarkers and coal type. Furthermore, findings at the molecular level corroborate petrographic observations regarding coal varieties.

The study suggests that swamp conditions and regional sedimentology are the key factors influencing Tertiary coal mineralogy, with local features such as ombrogenous settings, vegetation sediment traps and the level of contemporaneous sedimentation influencing the lateral distribution of mineral matter within seams. Furthermore, the quartz to kaolinite ratio

appears useful for the evaluation of the relative importance of silicate authigenesis and clastic input in these deposits

The success of this fully integrated multidisciplinary investigation of these coals and their local and regional palaeoenvironments illustrates the benefits of a holistic approach to coal research. Standard coal evaluation tools such as lithotype and micropetrographic assessment have been successfully integrated with organic geochemistry, coal mineralogy, and palaeobotanical evaluations to provide a fuller understanding of the relationships between the primary organic constituents, their likely palaeoenvironments and contemporary clastic sedimentation.

# BIBLIOGRAPHY


ALAM M. & PEARSON M. J. 1990. Bicadinanes in oils from the Surma Basin, Bangladesh. *Organic Geochemistry* **15**, 461-464.

ALEXANDER R., KAGI R. & NOBLE R. 1983. Identification of bicyclic sesquiterpenes Drimane and Eudesmane in petroleum. *Journal of the Chemical Society Chemical Communication*, 226-228.

ALEXANDER R., LARCHER A. V. & KAGI R. I. 1988. The use of plant derived biomarkers for correlation of oils with source rocks in the Cooper/Eromanga Basin system, Australia. *APEA Journal* **28 (1)**, 310-324.

ALLEY N. F. 1973. Landsurface development in the Mid North of South Australia. *Transactions of the Royal Society of South Australia* **97,** 1-16.

ALLEY N. F. 1991. Tertiary palaeoclimate in Southern Australia – A palynological perspective. *Geological Society of Australia, South Australian Division*, March Newsletter, 1-2.

ALLEY N. F. & LINDSAY J. M. 1995. Tertiary. *In* Drexel J. F. & Preiss W.V. eds., *The Geology of South Australia, Volume 2, The Phanerozoic*. Geological Survey of South Australia, Mines and Energy South Australia, Bulletin **54**, pp. 151-217.

AMIJAYA H. & LITTKE R. 2005. Microfacies and depositional environment of Tertiary Tanjung Enim low rank coal, South Sumatra Basin, Indonesia. *International Journal of Coal Geology* **61**, 197-221.

ANDERSON K. A. & MACKAY G. 1990. A review and reinterpretation of evidence concerning the origin of Victorian brown coal. *International Journal of Coal Geology* **16**, 327-347.

BALME B. E., KERSHAW A. P. & WEBB J. A. 1995. Floras of Australian coal measures, with notes on their associated Mesozoic faunas. *In* Ward C. R., Harrington H. J., Mallett C. W. & Beeston J. W. eds, *Geology of Australian Coal Basins*, Geological Society of Australia, Coal Geology Group, Special Publication **1**, pp. 41-62.

BARRICK R. C. & HEDGES J. I. 1981. Hydrocarbon geochemistry of the Puget Sound region-II. Sedimentary diterpenoid, steroid and triterpenoid hydrocarbons. *Geochimica et Cosmochimica Acta* **45**, 381-392.

BECHTEL A., SACHSENHOFER R. F., KOLCON I., GRATZER R., OTTO A. & PUTTMANN W. 2002. Organic geochemistry of the Lower Miocene Oberdorf lignite seam (Styian Basin, Austria): its relation to petrology, palynology and the palaeoenvironment. *International Journal of Coal Geology* **51**, 31-57.

BECHTEL A., GRUBER W., SACHSENHOFER R. F., GRATZER R., LUCKE A. & PUTTMANN W. 2003. Depositional environment of the Late Miocene Hausruck lignite (Alpine Foreland Basin): insights from petrology, organic geochemistry and stable carbon isotopes. *International Journal of Coal Geology* **53**, 153-180.

BECHTEL A., MARKIC M., SACHSENHOFER R. F., JELEN B., GRATZER R., LICKE A. & PUTTMANN W. 2004. Palaeoenvironment of the upper Oligocene Trbovlje coal seam (Slovenia). *International Journal of Coal Geology* **57**, 23-48.

BENDORAITIS J. G. 1973. Hydrocarbons of biogenic origin in petroleum - Aromatic triterpanes and bicyclic sesquiterpenes. *In* Tissot B. & Bienner F. eds., *Advances in Organic Geochemistry*. Editions Technip, Paris, pp. 209-224.

BERGGREN W. A. 1972. A Cenozoic time scale – some implications for regional geology and palaeogeography. *Lethaia* **5**, 195-215.

BLACK P. M. 1982. Petrology and inorganic geochemistry of South Island lignites, New Zealand. *Australian Coal Geology* **4**, 131-144.

BLOW W. H. 1969. Late middle Eocene to Recent planktonic foraminiferal biostratigraphy. *In* Bronniman P. & Rens H. H. eds., *Proceedings of the 1st International Conference on Planktonic Microfossils, 1967*, Geneva, **1**, 199-422.

BOEUF M. G. & DOUST H. 1975. Structure and development of the southern margin of Australia. *The APEA Journal* **15 (1)**, 33-43.

BOSTICK N. H. & DAWS T. A. 1994. Relationships between data from Rock-Eval pyrolysis and proximate, ultimate, petrographic and physical analysis of 142 diverse U.S. coal samples. *Organic Geochemistry* **21**, 35-49.

BRAKEL A. T., WILFORD G. E., TOTTERDELL J. M. & BRADSHAW M. 1995. Palaeogeographic settings of Australian coal measures. *In* Ward C.R., Harrington H. J.,

Mallett C. W. & Beeston J. W. eds, *Geology of Australian Coal Basins*, Geological Society of Australia Incorporated, Coal Geology Group, Special Publication **1**, pp. 1-15.

BROCKWAY D. J., OTTREY A. L. & HIGGINS R. S. 1991. Inorganic constituents. *In* Durie R. A. ed., *The Science of Victorian Brown Coal: Structure, Properties and Consequences for Utilization*. Butterworth-Heinemann, Oxford, pp. 598-651.

BROCKWAY D. J. & BOSARU R. M. 1985. Ion concentration profiles in Victorian brown coals. *Proceedings 1985 International Coal Science Conference*, Pergamon, Oxford, pp. 593-596.

BROCKWAY D. J. & HIGGINS R. S. 1991. Brown coal sampling, analysis and composition. *In* Durie R. A. ed., *The Science of Victorian Brown Coal: Structure, Properties and Consequences for Utilization*. Butterworth-Heinemann, Oxford, pp. 248-279.

CAMERON A. R., KALKREUTH W. D. & KOUKOUZAS C. 1984. The petrology of Greek brown coals. *International Journal of Coal Geology* **4**, 173-207.

CAMERON C. C., ESTERLE J. S. & PALMER C. A. 1989. The geology, botany and chemistry of selected peat-forming environment from temperate and tropical latitudes. *International Journal of Coal Geology* **12**, 105-156.

CASAGRANDE D. J. 1987. Sulphur in peat and coal. *In* Scott A. C. ed., *Coal and Coal-Bearing Strata: Recent Advances*, Geological Society Special Publication **32**, pp. 87-105.

CHAFFEE A. L. 1981. The organic geochemistry of Australian coals. PhD thesis, University of Melbourne (unpublished).

CHAFFEE A. L. & JOHNS R. B. 1985. Aliphatic components of Victorian brown coal lithotypes. *Organic Geochemistry* **8**, 349-365.

CHAFFEE A. L., HOOVER D. S., JOHNS R. B. & SCHEIGHARDT F. K. 1986. Biological markers extractable from coal. *In* Johns R. B. ed., *Biological Markers in the Sedimentary Record*. Elsevier, Amsterdam, pp. 311-345.

CHRISTOPHEL D. C. 1989. Evolution of the Australian flora through the Tertiary. *Plant Systematics and Evolution*, **162**, 63-78.

CHRISTOPHEL D. C. 1994. The early Tertiary macrofloras of continental Australia. *In* Hill S. H. ed., *History of the Australian Vegetation, Cretaceous to Recent*. Cambridge University Press, Cambridge, pp. 262–275.

COHEN A. D., SPACKMAN W. & DOLSEN P. 1984. Occurrence and distribution of sulphur in peat - forming environments of Southern Florida. *International Journal of Coal Geology* **4**, 73-96

COHEN A. D., SPACKMAN W. & RAYMOND R. Jr. 1987. Interpreting the characteristics of coal seams from chemical, physical and petrographic studies of peat deposits. *In* Scott A. C. ed., *Coal and Coal-Bearing Strata: Recent Advances*, Geological Society Special Publication **32**, pp. 107-125.

COOPER B. J. 1977. Tertiary stratigraphic nomenclature in the Inkerman – Balaklava Coalfield. *Quarterly Geological Notes, Geological Survey of South Australia* **61**, 2-6.

COOPER B. J. 1985. The Cainozoic St. Vincent Basin - tectonics, structure, stratigraphy. *In* Lindsay J. M. ed., *Stratigraphy, Palaeontology, Malacology*. Special Publication South Australian Department of Mines and Energy **5**, pp. 35-49.

CHRISTOPHEL D. C. 1989. Evolution of the Australian Flora through the Tertiary. *Plant Systematics and Evolution* **162**, 63-78.

CHRISTOPHEL D. C. 1994. The early Tertiary macrofloras of continental Australia. *In* Hill R. S. ed., *History of the Australian vegetation: Cretaceous to Recent*, Cambridge University Press, Cambridge, pp. 262-275.

CROSDALE P. J. 1993. Coal maceral ratios as indicators of environment of deposition: do they work for ombrogenous mires? An example from the Miocene of New Zealand. *Organic Geochemistry* **20**, 797-809.

CROSDALE P. J. 1995. Lithotype sequences in Early Miocene Maryville Coal Measures, New Zealand. *International Journal of Coal Geology* **28**, 37-50.

CROSDALE P. J. 2004. Coal facies studies in Australia. *International Journal of Coal Geology* **58**, 125-130.

CROSDALE P. J., SOROKIN A. P., WOOLFE K. J. & MACDONALD D. I. M. 2002. Inertinite-rich Tertiary coals from the Zeya-Bureya Basin, Far Eastern Russia. *International Journal of Coal Geology* **51**, 215-235.

CURIALE J. A. 1995. Saturated and olefinic terrigenous triterpenoid hydrocarbons in a biodegraded Tertiary oil of northeast Alaska. *Organic Geochemistry* **23**, 177-182.

CURIALE A. J. & LIN R. 1991. Tertiary deltaic and lacustrine organic facies: comparison of biomarker and kerogen distributions. *Organic Geochemistry* **17**, 785-803.

DAVIES R., DIESSEL, C., HOWELL J., FLINT S. & BOYD R. 2005. Vertical and lateral variation in the petrography of the Upper Cretaceous Sunnyside coal of eastern Utah, USA-implications for the recognition of high resolution accommodation changes in paralic coal seams. *International Journal of Coal Geology* **61**, 13-33.

DAVIS A., RUSSELL S. J., RIMMER S. M. & YEAKEL J. D. 1984. Some genetic implications of silica and aluminosilicates in peat and coal. *International Journal of Coal Geology* **3**, 293-314.

DEL RIO J. C., GONZALEZ-VILA F. J. & MARTIN F. 1992. Variation in the content and distribution of biomarkers in two closely situated peat and lignite deposits. *Organic Geochemistry* **18**, 67-78.

DEHMER J. 1993. Petrology and organic geochemistry of peat samples from a raised bog in Kalimantan (Borneo). *Organic Geochemistry* **20**, 349-362.

DEHMER J. 1995. Petrological and organic geochemical investigation of recent peats with known environments of deposition. *International Journal of Coal Geology* **28**, 111-138.

DEHMER J. 2004. A short report on the investigations made on the facies of German coal deposits. *International Journal of Coal Geology* **58**, 41-51.

DIESSEL C .F. K. 1980. Coal Geology. Australian Mineral Foundation workshop course 137/80 (unpublished).

DIESSEL C. F. K. 1982. An appraisal of coal facies based on maceral characteristics. *Australian Coal Geology* **4**, 474-483.

DIESSEL C. F. K. 1986. On correlation between coal facies and depositional environments. *20$^{th}$ Newcastle Symposium on Advances in the Study of the Sydney Basin.* Proceedings Publication 246, Department of Geology, University of Newcastle, Australia, pp. 19-22.

DIESSEL C. F. K. 1992. *Coal-Bearing Depositional Systems*. Springer-Verlag, Berlin, 721 p.

DIESSEL C. F. K. & SMYTH M. 1995. Petrographic constituents of Australian coals. *In* Ward C. R., Harrington H. J., Mallett C. W. & Beeston J. W. eds, *Geology of Australian Coal Basins*, Geological Society of Australia, Coal Geology Group, Special Publication **1**, pp. 63-81.

DIESSEL C. F. K., BOYD R., WADSWORTH J., LECKIE D. & CHALMERS G. 2000. On balanced and unbalanced accommodation/peat accumulation ratios in the Cretaceous coals from Gates Formation, Western Canada, and their sequence-stratigraphic significance. *International Journal of Coal Geology* **43**, 143-186.

DISNAR J.R. & HAROUNA M. 1994. Biological origin of tetracyclic diterpanes, *n* -alkanes and other biomarkers found in Lower Carboniferous Gondwana coals (Niger). *Organic Geochemistry* **21**, 143-152.

DURIE R. A. & SWAINW D. J. 1971. Inorganic constituents of coal. *Coal Research in CSIRO* **45**, 9-18

ELIAS V. O., CARDOSO J. N. & SIMONEIT B. R. T. 1996. Sesquiterpenoids in Amazon shelf waters. *Organic Geochemistry* **25**, 241-250.

EGLINTON G. & HAMILTON R. J. 1967. Leaf epicuticular waxes. *Science,* **156**, 1322-1335.

ERCEGOVAC M., ZIVOTIC D. & KOSTIC A. 2006. Genetic-industrial classification of brown coals in Serbia. *International Journal of Coal Geology* **68**, 39-56.

ESTERLE J. S. & FERM J. 1986. Relationship between petrographic and chemical properties and coal seam geometry, Hance Seam, Breathitt Formation, southeastern Kentucky. *International Journal of Coal Geology* **6**, 199-214.

ETSA COAL RESOURCES DEPARTMENT 1983. Lochiel Coal Deposit – Geological Report. Electricity Trust of South Australia (unpublished).

ETSA COAL RESOURCES DEPARTMENT 1988a. Lochiel Deposit - Preliminary Resource Statement. Electricity Trust of South Australia (unpublished).

ETSA COAL RESOURCES DEPARTMENT 1988b. Lochiel Deposit – Run of mine coal quality, procedures for calculation. Electricity Trust of South Australia (unpublished).

ETSA COAL RESOURCES DEPARTMENT 1988c. Lochiel Trial Pit – Coal Geology Report. Electricity Trust of South Australia (unpublished).

FERM J. C. & STAUB J. R. 1984. Depositional controls of mineable coal bodies. *In* Rahmani R. A. & Flores R. M. eds., *Sedimentology of Coal and Coal-Bearing Sequences*. Special Publication **7**, International Association of Sedimentologists. Blackwell, Oxford, pp. 275-289.

FIELDING C. R. 1985. Coal depositional models and the distinction between alluvial and delta plain environments. *International Journal of Coal Geology* **5**, 41-48.

FIELDING C. R. 1988. Coal depositional environments. *In* Fielding C. R. & Draper J. J. conveners, *Depositional Environments of Coal-bearing Sequences: Examples from Queensland Coal Basins.* Australian Sedimentologists Group workshop notes (unpublished).

FLORES R. M. 1989. Rocky Mountain Tertiary coal-basin models and their applicability to some world basins. *International Journal of Coal Geology* **12**, 767-798.

FLORES R. M. 1993. Geologic and geomorphic controls on coal development in some Tertiary, Rocky Mountain basins, USA. *International Journal of Coal Geology* **23**, 43-73.

FLORES R. M. & SYKES R. 1996. Depositional controls on coal distribution and quality in the Eocene Brunner Coal Measures, Buller Coalfield, South Island, New Zealand. *International Journal of Coal Geology* **29**, 291-336.

FRANCIS W. 1961. *Coal: Its Formation and Composition.* Edward Arnold, London, 806 p.

G & S RESOURCES 1984. Lochiel Coal Deposit, 1984 bulk sample geological report. Report to the Electricity Trust of South Australia (unpublished).

G & S RESOURCES 1993. Bowmans Coal Deposit, geological database update and modelling. Report to the Electricity Trust of South Australia (unpublished).

GALLOWAY W. E. & HOBDAY D. K. 1983. *Terrigenous Depositional Systems: Applications to Petroleum, Coal and Uranium Exploration.* Springer-Verlag, New York, 423 p.

GAVETT K. L. & FERM J. C. 1985. Coal quality and depositional setting of the Mudseam Coal, northeastern Kentucky. *Geological Society of America, Abstracts with Programs* **17 (2)**, pp. 92.

GEORGE A. M. 1972. Petrological Report No. 13, Pale coal lithotype in the Latrobe Valley Coal Measures. Report to the State Electricity Commission of Victoria (unpublished).

GEORGE A. M. 1975. Petrological Report No. 17, Brown coal lithotypes in the Latrobe Valley Deposits. Report to the State Electricity Commission of Victoria (unpublished).

GEORGE A. M. 1982. Latrobe Valley brown coal - lithotypes, macerals, coal properties. *Australian Coal Geology* **4**, 111-130.

GEORGE A. M., BROCKWAY D. J., STACY W. O. & KISS L. T. 1984. The origin of minerals, inorganics and sulphur in brown coal. *Advances in the Study of the Sydney Basin*, Proc. of the 18th Symposium, Newcastle, pp. 67-69.

GEORGE A. M. & MACKAY G. A. 1991. Petrology. *In* Durie R. A. 1991 ed., *The Science of Victorian Brown Coal: Structure, Properties and Consequences for Utilization.* Butterworth-Heinemann, Oxford, pp. 45-102.

GLASSPOOL I. J. 2003. Hypautochthonous-allochthonous coal deposition in the Permian, South African, Whitbank Basin No. 2 seam: a combined approach using sedimentology, coal petrology and palaeontology. *International Journal of Coal Geology* **53**, 81-135.

GLOE C. S. & HOLDGATE G. R. 1991. Geology and Resources. *In* Durie R. A. 1991 ed., *The Science of Victorian Brown Coal:Structure, Properties and Consequences for Utilization.* Butterworth-Heinemann, Oxford, pp. 1-43.

GOODARZI F. 1985. Organic petrology of Hat Creek Coal Deposit No. 1, British Columbia. *International Journal of Coal Geology* **5**, 377-396.

GRANTHAM P. J. & DOUGLAS A. G. 1980. The nature and origin of sesquiterpenoids in some Tertiary fossil resins. *Geochimica et Cosmochimica Acta* **44**, 1801-1810.

GRANTHAM P. J., POSTHUMA J. & BAAK A. 1983. Triterpanes in a number of far-eastern crude oils. *In* Bjoroy. M. ed., *Advances in Organic Geochemistry 1981*, John Wiley & Sons, New York, pp. 675-683.

GRIMALT J. O., SIMONEIT B. R. T., HATCHER P. G. & NISSENBAUM A. 1988. The molecular composition of ambers. *Organic Geochemistry* **13**, 677-690.

HACQUEBARD P. A. & DONALDSON J. R. 1969. Carboniferous coal deposition associated with flood-plain and limnic environments in Nova Scotia. *Geological Society of America Special Publication* **114**, 143-191.

HAGELSKAMP H. H. B., ERIKSSON P. G. & SNYMAN C. P. 1988. The effect of depositional environment on coal distribution and quality parameters in a portion of the Highveld Coalfield, South Africa. *International Journal of Coal Geology* **10**, 51-77.

HAGEMANN H. W. & HOLLERBACH A. 1980. Relationships between the macropetrographic and organic geochemical composition of lignites. *In* Douglas A.G. and Maxwell J.R. eds., *Advances in Organic Geochemistry 1979*. Pergamon, Oxford, pp. 631-638.

HAGEMANN H. W. & WOLF M. 1987. New interpretations of the facies of the Rhenish Brown Coal of West Germany. *International Journal of Coal Geology* **7**, 335-348.

HAGER H. 1993. The origin of the Tertiary lignite deposits of the Lower Rhine region, Germany. *International Journal of Coal Geology* **23**, 251-262.

HAQ B. U., HARDENBOL J. & VAIL P. R. 1988. Mesozoic and Cenozoic chronostratigraphic and cycles of sea-level change, *In* Wilgus C. K., Hastings B. S., Kendell C. G. St. C, Posamentier H. W, Ross C. A. & Van Wagoner J. C. eds., *Sea-level Changes: An Integrated Project*. SEPM Special Publication **52**, pp. 71-109.

HARRIS W. K. 1966. New and redefined names in South Australian Lower Tertiary Stratigraphy. *Quarterly Geological Notes, Geological Survey of South Australia* **20**, 1-3.

HARRIS W. K. 1982. Palynological examination of 4 samples, borehole V462C, Lochiel, South Australia. Report to The Electricity Trust of South Australia (unpublished).

HARRIS W. K. 1983. ETSA – Lochiel Report. Report to The Electricity Trust of South Australia (unpublished).

HARRIS W. K. 1985. Middle to Late Eocene depositional cycles and dinoflagellate zones in southern Australia. *In* Lindsay J. M. ed., *Stratigraphy, Palaeontology, Malacology*. Special Publication South Australian Department of Mines and Energy, **5**, pp. 133-144.

HAZAI I., ALEXANDER G., ESSIGER B. & SZEKELY T. 1988. Identification of aliphatic biological markers in brown coals. *Fuel* **67**, 973-982.

HIGGINS R. S., KISS L. T., ALLARDICE D. J., GEORGE A. M. & KING T. N. W. 1980. Properties of brown coals from the Latrobe Valley – A basis for the evaluation of quality. State Electricity Commission of Victoria, Research and Development Department, Brown Coal Research Division, report number SC/80/17 (unpublished).

HILLWOOD E. R. 1961. Inkerman – Balaklava Coalfield. *South Australian Department of Mines, Mining Review* **112**, 26-34.

HODGES N. J., LADNER W. R. & MARTIN T. G. 1983. Chlorine in coal: A review of its origin and mode of occurrence. *Journal of the Institute of Energy* **56**, 158-169.

HOLDGATE G. R. 1985. Latrobe Valley brown coals – their geometry and facies equivalents as a guide to depositional environment. *Australian Coal Geology* **5**, 53-68.

HOLDGATE G. R., KERSHAW A. P. & SLUITER I .R. K. 1995. Sequence stratigraphic analysis and the origins of Tertiary brown coal lithotypes, Latrobe Valley, Gippsland Basin, Australia. *International Journal of Coal Geology* **28**, 249-275.

HOLDGATE G. R. & CLARKE D. A. 2000. A review of Tertiary brown coal deposits in Australia – Their depositional factors and eustatic correlations. *AAPG Bulletin* **84**,1129-1151.

HOLDGATE G. R., WALLACE M. W., GALLAGHER S. J. & TAYLOR D. 2000. A review of the Taralgon Formation in the Gippsland Basin – a world class brown coal resource. *International Journal of Coal Geology* **45**, 55-84.

HOLZ M., KALKREUTH W. & BANERJEE I. 2002. Sequence stratigraphy of paralic coal bearing strata: an overview. *International Journal of Coal Geology* **48**, 147-179.

HORWITZ R. C. 1959. The geology of the Wakefield sheet. *Report of Investigations, Geological Survey of South Australia* **18**, 1-32.

HOSTETTLER F. D., RAPP J. B., KVENVOLDEN K. A. & LUOMA S. N. 1989. Organic markers as source discriminants and sediment transport indicators in south San Francisco Bay, California. *Geochimica et Cosmochimica Acta* **53**, 1563-1576.

HUNT J. W. 1982. Petrographic characteristics of Australian coals in a geological context. *Symposium on Characteristics of Australian Coals and their Consequences for Utilization*, CSIRO North Ryde, NSW. Abstracts and papers, pp. 5-1–5-5.

HUNT J. W. & HOBDAY D. K. 1984. Petrographic composition and sulphur content of coals associated with alluvial fans in Permian Sydney and Gunnedah Basins, eastern Australia. *In* Rahmani R.A. & Flores R.M. eds., *Sedimentology of Coal and Coal-bearing Sequences*. Special Publication **7**, International Association of Sedimentologists. Blackwell, Oxford, pp. 43-60.

INTERNATIONAL COMMITTEE FOR COAL PETROLOGY 1971. *International Handbook of Coal Petrology*. Supplement to the 2nd edition. Centre National de la Recherche Scientifique, Paris.

INTERNATIONAL COMMITTEE FOR COAL AND ORGANIC PETROLOGY 1993. *International Handbook of Coal Petrology*. 3rd supplement to the 2nd edition. International Committee for Coal Petrology, University of Newcastle-upon-Tyne.

INTERNATIONAL COMMITTEE FOR COAL AND ORGANIC PETROLOGY 1998. The new vitrinite classification (ICCP System 1994). *Fuel* **77**, 349-358.

INTERNATIONAL COMMITTEE FOR COAL AND ORGANIC PETROLOGY 2001. The new inertinite classification (ICCP System 1994). *Fuel* **80**, 459-471.

JOHNSON D. P. 1995. Palaeoclimate and depositional settings of Australian coal measures. *In* Ward C. R., Harrington H. J., Mallett C. W. & Beeston J. W. eds., *Geology of Australian Coal Basins*. Geological Society of Australia, Coal Geology Group, Special Publication **1**, pp. 17-39.

JOHNSON W. 1960. Coal exploration, Northern end of the St. Vincent Basin. *South Australian Department of Mines, Mining Review* **110**, 134-144.

KALKREUTH W. & LECKIE D. A. 1989. Sedimentological and petrographical characteristics of Cretaceous strandplain coals: a model for coal accumulation from the North America Western Interior Seaway. *International Journal of Coal Geology* **12**, 381-424.

KALKREUTH W. D., MARCHIONI D. L., CALDER J. H., LAMBERSON M. N., NAYLOR R. D. & PAUL J. 1991. The relationship between coal petrography and depositional environments from selected coal basins in Canada. *International Journal of Coal Geology* **19**, 21-76.

KERSHAW A. P. & SLUITER I. R. 1982. The application of pollen analysis to the elucidation of Latrobe Valley brown coal depositional environments and stratigraphy. *Australian Coal Geology* **4**, 169-186.

KERSHAW A. P., BOLGER P. F., SLUITER I. R., BAIRD J. G. & WHITELAW M. 1991. The nature and evolution of lithotypes in the Tertiary brown coals of the Latrobe Valley, southeastern Australia. *International Journal of Coal Geology* **18**, 233-249.

KEMP E. M. 1981. Tertiary palaeogeography and the evolution of Australian Climate. *In* Keast A. ed., *Ecological Biogeography of Australia.* Dr. W Junk, The Hague, pp. 33-46.

KILLOPS S. D. & FREWIN N. L. 1994. Triterpenoid diagenesis and cuticular preservation. *Organic Geochemistry* **21**, 1193-1209.

KILLOPS S. D., RAINE J. I., WOOLHOUSE A. D. & WESTON R. J. 1995. Chemostratigraphic evidence of higher-plant evolution in the Taranaki Basin, New Zealand. *Organic Geochemistry* **23**, 429-445.

KING T. N. W., GEORGE A. M., HIBBERT W. D. & KISS L. T. 1983. Variation of coal properties with lithotype. Part 2: Latrobe Valley coals. State Electricity Commission of Victoria, Research and Development Department, Brown Coal Research Division, Report SO/83/55 (unpublished).

KISS L. T., BROCKWAY D. J., GEORGE A. M. & STACY W. O. 1985. The distribution of minerals, inorganics and sulphur in brown coal. *Proceedings 1985 International Conference on Coal Science, Sydney.* Pergamon, Sydney, pp. 589-592.

KISS L. T. & KING T. N. 1977. The expression of results of coal analysis: the case for brown coals. *Fuel* **56**, 340-341.

KOLCON I. & SACHSENHOFER R. F. 1999. Petrography, palynology and depositional environments of the early Miocene Oberdorf lignite seam (Styian Basin, Austria). *International Journal of Coal Geology* **41**, 275-308.

KRAVITS C. M. & CRELLING J. C. 1981. Effects of overbank deposition on the quality and maceral composition of the Herrin (No. 6) Coal (Pennsylvanian) of Southern Illinois. *International Journal of Coal Geology* **1**, 195-212.

KREMOR A. G. 1986. Depositional environments of the Lochiel Coal Deposit. Report to the Electricity Trust of South Australia, (unpublished).

KREMOR A. G. 1992. Engineering geological factors effecting slope stability on soft brown coal deposits – A South Australian Example. PhD Thesis, University of Adelaide, Adelaide (unpublished).

KREMOR A. G. & SPRINGBETT G. M. 1995. St. Vincent Basin – Lochiel and Bowmans Deposits. *In* Ward C. R., Harrington H. J., Mallett C. W. & Beeston J. W. eds, *Geology of Australian Coal Basins.* Geological Society of Australia Incorporated, Coal Geology Group, Special Publication **1**, pp. 580-582.

LAMBERSON M. N., BUSTIN R. M. & KALKREUTH W. 1991. Lithotype (maceral) composition and variation as correlated with paleo-wetland environments, Gates Formation, northeastern British Columbia Canada. *International Journal of Coal Geology* **18**, 87-124.

LI M. & JOHNS R. B. 1990. Kerogen extract interrelationships of terpenoid biomarkers from a Jilin brown coal. *Organic Geochemistry* **15**, 109-121.

LI M., JOHNS R. B. & MEI B. 1990. A study in early diagenesis: Biomarker composition of a suite of immature coals and coaly shales. *Organic Geochemistry* **16**, 1067-1075.

LINDSAY J. M. 1981. Tertiary stratigraphy and foraminifera of the Adelaide city area, St. Vincent Basin, South Australia. MSc Thesis, University of Adelaide, Adelaide (unpublished).

LINDSAY J. M. & ALLEY N. F. 1995. St. Vincent Basin. *In* Drexel J. F. & Preiss W. V. eds., *The Geology of South Australia, Volume 2 The Phanerozoic.* Geological Survey of South Australia, Mines and Energy South Australia, Bulletin **54**, pp. 163-172.

LIVSEY A., DOUGLAS A. G. & CONNAN J. 1984. Diterpenoid hydrocarbons in sediments from and offshore (Labrador) well. *Organic Geochemistry* **6,** 73-81.

LOGAN G. A. & EGLINTON G. 1994. Biogeochemistry of the Moicene lacustrine deposit at Clarkia, northern Idaho, U.S.A. *Organic Geochemistry* **21**, 857-870.

LU S.-T. & KAPLAN I. R. 1992. Diterpanes, triterpanes, steranes, and aromatic hydrocarbons in natural bitumens and pyrolysates from different humic coal. *Geochimica et Cosmochimica Acta* **56**, 2761-2788.

MANUEL J. R. 1988. Identification, preservation and palaeoenvironmental interpretation of Tertiary coalified wood from South Australia. BSc (Hons) thesis, University of Adelaide, Adelaide (unpublished).

MANUEL J. R. & QUAST K. B. 1990. South Australian low-rank coal study - Reactions occurring in South Australian low-rank coal ashes during combustion. Report to the State Energy Research Advisory Committee by the Metallurgy Department, South Australian Institute of Technology (unpublished).

MACKAY G. H., ATTWOOD D. H., GAULTON R. J. & GEORGE A. M. 1985. The cyclic occurrences of brown coal lithotypes. State Electricity Commission of Victoria, Report S0/85/93 (unpublished).

MACPHAIL M. K., ALLEY N. F., TRUSWELL E. M. & SLUITER I. R. K. 1994. Early Tertiary vegetation: evidence from spores and pollen. *In* Hill S. H. ed., *History of the Australian Vegetation, Cretaceous to Recent*. Cambridge University Press, Cambridge, pp. 189-261.

MARCHIONI D. & KALKREUTH W. 1991. Coal facies interpretations based on lithotype and maceral variations in Lower Cretaceous (Gates Formation) coals of Western Canada. *International Journal of Coal Geology* **18**, 125-162.

MAVRIDOU E., ANTONIADIS P., KHANAQA P. & GENTZIS T. 2003. Palaeoenvironmental interpretation of the Amynteon-Ptolemaida lignite deposit in northern Greece based on its petrographic composition. *International Journal of Coal Geology* **56**, 253-268.

McCABE P. J. 1987. Facies studies of coal and coal-bearing strata. *In* Scott A. C. ed., *Coal and Coal-bearing Strata: Recent Advances*. Geological Society Special Publication, **32**, pp. 51-66.

MEAKIN S. 1985. Palynological analysis of the Clinton Coal Measures, northern St. Vincent Basin, South Australia. BSc (Hons) thesis, University of Adelaide (unpublished).

MERRITT R. D. 1987. Petrology of Tertiary and Cretaceous coals of southern Alaska. *International Journal of Coal Geology* **9**, 129-156.

MEYER G. M. 1976. Tertiary brown coal deposits in the northern St. Vincent Basin, South Australia. Department of Mines South Australia report, Report Book 796 (unpublished).

MEYER G. M. 1992. Geological results from the 1977/78 drilling program, Wakefield and Clinton Deposits. Department of Mines and Energy South Australia, Report Book 79/82 (unpublished).

MICHAELSON P. & HENDERSON R. A. 2000. Facies relationships and cyclicity of high-latitude, Late Permian coal measures, Bowen Basin, Australia. *International Journal of Coal Geology* **44**, 19-48.

MILLER R. N. & GIVEN, P. H. 1985. A geochemical study of the inorganic constituents in some low rank coals. Report from Coal Research Section, The Pennsylvania State University (unpublished).

MING Q., XILIN R., DAZHONG T., JIAN X. & WOLF M. 1994. Petrographic and geochemical characterisation of pale and dark brown coal from Yunan Province, China. *International Journal of Coal Geology* **25**, 65-92.

MOLDOWAN J. M., DAHL J., HUIZINGA J., FAGO F. J., HICKEY L. J., PEAKMAN T. M. & TAYLOR D. W. 1994. The molecular fossil record of oleanane and its relation to angiosperms. *Science* **265**, 768-771.

MOORE P. D. 1987. Ecological and hydrological aspects of peat formation. *In* Scott A. C. ed., *Coal and Coal-Bearing Strata: Recent Advances*, Geological Society Special Publication **32**, pp. 7-15.

MOORE P. D. 1989. The ecology of peat-forming processes: a review. *International Journal of Coal Geology* **12**, 89-103.

MOORE P. D. 1995. Biological processes controlling the development of modern peat-forming ecosystems. *International Journal of Coal Geology* **28**, 99-110.

MOORE T. A., STANTON R. W., POCKNALL D. T. & GLORES R. M. 1990. Maceral and palynomorph facies of two Tertiary peat-forming basins in the Powder River Basin, U.S.A. *International Journal of Coal Geology* **15**, 293-316.

MOORE T. A. & SHEARER J. C. 2003. Peat/coal and depositional environment – are they related? *International Journal of Coal Geology* **56**, 233-252.

MOSHONAS M. G. & LUND E. D. 1970. The mass spectra of sesquiterpene hydrocarbons. *The Flavour Industry* **June 1970**, 375-378.

MUKOPADHYAY P. K. 1986. Petrography of selected Wilcox and Jackson Group lignites from the Tertiary of Texas. *In* Finkelman R. B. & Casagrande D. J. eds., *Geology of Gulf Coast Lignites*. Environmental and Coal Associates, pp. 126-145.

MURRAY A. P., SOSROWIDJOJO I. B., ALEXANDER R., KAGI R. I., NORGATE C. M. & SUMMONS R. E. 1997. Oleananes in oils and sediments: evidence of marine influence during early diagenesis. *Geochimica et Cosmochimica Acta* **61**, 1261-1276.

NICHOLS D. J. & TRAVERSE A. 1971. Palynology, petrology and depositional environments in some early Tertiary lignites in Texas. *Geoscience and Man* **III**, 37-48.

NOBLE R. A., ALEXANDER R., KAGI R. I. & KNOX J. 1985. Tetracyclic diterpenoid hydrocarbons in some Australian coals, sediments and crude oils. *Geochimica et Cosmochimica Acta* **49**, 2141-2147.

NOBLE R. A., ALEXANDER R., KAGI R.I. & KNOX J. 1986. Identification of some diterpenoid hydrocarbons in petroleum. *Organic Geochemistry* **10,** 825-829.

NORGATE C. M., ALEXANDER R. & KAGI R. I. 1997. Identification of sulphur-bound hydrocarbons in an Eocene marine influenced lignite. *18th International Meeting on Organic Geochemistry, Maastrricht, The Netherlands*, Abstracts, pp. 61-62.

OTTO A., WALTHER H, & PUTTMANN W. 1997. Sesqui- and diterpenoid biomarkers preserved in *Taxodium* -rich Oligocene oxbox lake clays, Weisselster Basin, Germany. *Organic Geochemistry* **26**, 105-115.

PETERS K. E. & MOLDOWAN J. M. 1993. *The Biomarker Guide. Interpreting Molecular Fossils in Ancient Sediments.* Prentice Hall, New Jersey, 363 p.

PETERS K. E., WALTERS C. C. & MOLDOWAN J. M. 2004. *The Biomarker Guide; Second Edition, II Biomarkers and Isotopes in Petroleum Systems and Earth History.* Cambridge University Press, 700 p.

PETROV A. A., VOROBIEVA N. S. & ZEMSKOVA Z. K. 1985. Sterenes and triterpenes in brown coals. *Organic Geochemistry* **8**, 269-273.

PHILP R. P. 1985. *Fossil Fuel Biomarkers. Applications and Spectra.* Elsevier, Amsterdam, 294 p.

PRIESS W. V. 1993. Neoproterozoic. *In* Drexel J. F., Preiss W. V. & Parker A. J. eds., *Geology of South Australia, Volume 1: The Precambrian*. Geological Survey of South Australia, Bulletin **54**, pp. 170-204.

QUAST K. B. & READETT D. J. 1991. Minerals and inorganic components associated with South Australian lignites. *In* Schobert H. H., Bartle K. D. & Lynch L. L. eds., *Coal Science II*, American Chemical Society, Washington DC, pp, 20-29.

QUIRK M. M., WARDROPER A. M. K., WHEATLEY R. E. & MAXWELL J. R. 1984. Extended hopanoids in peat environments. *Chemical Geology* **42**, 25-43.

RAYMOND R., CAMERON C. C. & COHEN A. D. 1987. Relationship between peat geochemistry and depositional environments, Cranberry Island, Maine. *International Journal of Coal Geology* **8**, 175-187.

READETT D. J. & QUAST K. B. 1987. Minerals and inorganics associated with South Australian lignites - Final report. Report to State Energy Research Advisory Committee by School of Metallurgy, South Australian Institute of Technology (unpublished).

RIVA A., CACCIALANZA P. G. & QUAGLIAROLI F. 1988. Recognition of 18ß(H)-oleanane in several crudes and Tertiary - Upper Cretaceous sediments. Definition of a new maturity parameter. *Organic Geochemistry* **13**, 671-675.

ROLLINS M. S., COHEN A. D. & DURIG J. R. 1993. Effects of fires on the chemical and petrographic composition of peat in the Snuggedy Swamp, South Carolina. *International Journal of Coal Geology* **22**, 101-117.

ROWETT A. I. 1992. Dispersed cuticular floras of South Australian Tertiary coalfields, Part 2: Lochiel. *Transactions of the Royal Society of South Australia* **116**, 95-107.

ROWETT A. I. 1997. Preliminary report of palaeodrainage in the St. Vincent Basin and Mt. Lofty Ranges. Mines and Energy Resources South Australia, Report Book 97/25 (unpublished).

ROWETT A. I. & STOIAN L. 1999. Lochiel Palynology. Primary Industries and Resources South Australia Memo (unpublished).

RULLKÖTTER J., LEYTHAEUSER D. & WENDISCH D. 1982. Novel 23,28-bisnorlupanes in Tertiary sediments. Widespread occurrence of nuclear demethylated triterpanes. *Geochimica et Cosmochimica Acta* **46**, 2501-2509.

RULLKÖTTER J., PEAKMAN T. M. & TEN HAVEN H. L. 1994. Early diagenesis of terrigenous triterpenoids and its implications for petroleum geochemistry. *Organic Geochemistry* **21**, 215-233.

SCHAFER H. N. S. 1991. Functional groups and ion exchange properties. *In* Durie R.A. ed., *The Science of Victorian Brown Coal: Structure, Properties and Consequences for Utilization*. Butterworth-Heinemann , Oxford, pp. 324-360.

SCHMITTER J. M., SUCROW W. & ARPINO P. J. 1982. Occurrence of novel tetracyclic geochemical markers; 8,14-seco-hopanes in Nigerian crude oil. *Geochimica et Cosmochimica Acta* **46**, 2345-2350.

SCHULZE T. & MICHAELIS W. 1989. Structure and origin of terpenoid hydrocarbons in some German coals. *Organic Geochemistry* **16**, 1051-1058.

SCOTT A. C. 1989. Observations on the nature and origin of fusain. *International Journal of Coal Geology* **12**, 443-475.

SCOTT A. C. 2002. Coal petrology and the origin of coal macerals: a way ahead? *International Journal of Coal Geology* **50**, 119-134.

SHEARER J. C., MOORE T. A. & DEMCHUK T. D. 1995. Delineation of the distinctive nature of Tertiary coal beds. *International Journal of Coal Geology* **28**, 71-98.

SHERWOOD A. M. 1986. An outline of the geology of New Zealand coalfields. *New Zealand Geological Survey Record* **7,** New Zealand Geological Survey, 27 p.

SHENG G., SIMONEIT B. R. T., LEIF R. N., CHEN X. & FU J. 1992. Tetracyclic terpanes enriched in Devonian cuticle humic coals. *Fuel* **71**, 523-532.

SHIBAOKA M. 1972. Silica/alumina ratios of the ashes from some Australian coals. *Fuel* **51**, 278-283.

SILVA M. B. & KALKREUTH W. 2005. Petrological and geochemical characterization of Candiota coal seams, Brazil – Implication for coal facies interpretations and coal rank. *International Journal of Coal Geology* **64**, 217-238.

SIMONEIT B. R. T., GRIMALT J. O., WANG T. G., COX R. E., HATCHER P. C. & NISSENBAUM A. 1986. Cyclic terpenoids of contemporary resinous detritus and fossil woods, ambers and coals. *Organic Geochemistry* **10**, 877-889.

SINGH R. K., ALEXANDER R., & KAGI R. I. 1994. Identification and occurrence of norcadalenes and related compounds in crude oil and sediments. *Organic Geochemistry* **21**, 249-256.

SLUITER I .R. K, KERSHAW A. P., HOLDGATE G. R. & BULMAN D. 1995. Biogeographic, ecological and stratigraphic relationships of the Miocene brown coal floras, Latrobe Valley, Victoria, Australia. *International Journal of Coal Geology* **28**, 227-302.

SMYTH M. 1977. The petrology of some Tertiary brown coals from South Australia. CSIRO Mineral Research Laboratories, Report 899R (unpublished).

SMYTH M. 1984. Coal microlithotypes related to sedimentary environments in the Cooper Basin. *In* Rahmani R. A. & Flores R. M. eds., *Sedimentology of Coal-bearing Sequences*. International Association of Sedimentologists, Special Publication **7**, pp. 333-347.

SMYTH M. 1989. Organic petrology and clastic depositional environments with special reference to Australian coal basins. *International Journal of Coal Geology* **12**, 635-656.

SMYTH M. & COOK A. C. 1976. Sequence in Australian coal seams. *Mathematical Geology* **8**, 529-547.

SMYTH M. & HARRISON J. 1976. Petrology of some coals from the Inkerman-Balaklava Coalfield, South Australia. CSIRO Mineral Research Laboratories, Report 823R (unpublished).

SPRINGBETT G. M. 1980. Northern St. Vincent Basin Coalfield South Australia, geological report. Report to the Electricity Trust of South Australia (unpublished).

SPRINGBETT G. M. 1981. Geological investigation of the Bowmans trial pit. Report to the Electricity Trust of South Australia (unpublished).

SPRINGBETT G. M. & McKIRDY D. M. 1999. Late Eocene soft brown coals from the northern St. Vincent Basin: organic facies and biomarker signatures. *19th International Meeting on Organic Geochemistry, Istanbul, Turkey, Abstracts*, pp. 579-580.

STACH E., MACKOWSKY M-Th., TEICHMULLER M., TAYLOR G. M., CHANDRA D. & TEICHMULLER R. 1982. *Stach's Textbook of Coal Petrology*. Gebruder

Borntraeger, Berlin, 535 p.

STANDARDS ASSOCIATION OF AUSTRALIA 1971. Coal and coke – Analysis and testing – Ultimate analysis of higher rank coal – Determination of total sulphur (Eschka method). *Australian Standard,* **AS 1038.6**.

STANDARDS ASSOCIATION OF AUSTRALIA 1979. Coal and coke – Analysis and testing – Proximate analysis of higher rank coal. *Australian Standard* **AS 1038.3**.

STANDARDS ASSOCIATION OF AUSTRALIA 1979. Coal and coke – Analysis and testing – Higher rank coal ash and coke ash – Major and minor elements – Borate fusion/flame atomic absorption spectrometric method. *Australian Standard* **AS 1038.14.1**.

STANDARDS ASSOCIATION OF AUSTRALIA 1981. Methods for the analysis and testing of lower rank coals and its chars – Determination of total moisture content of lower rank coal. *Australian Standard* **AS 2434.1**.

STANDARDS ASSOCIATION OF AUSTRALIA 1982. Glossary of terms relating to solid mineral fuels, Part 3 – Terms relating to brown coal. *Australian Standard* **AS 2418.3**.

STANDARDS ASSOCIATION OF AUSTRALIA 1987. Classification and coding systems for Australian coals. *Australian Standard* **AS 2096**.

STANDARDS AUSTRALIA 1998. Coal petrography. Part 2: Maceral analysis. *Australian Standard* **AS 2856.2**.

STANDARDS AUSTRALIA 2000. Coal petrography – Preparation of coal samples for incident light microscopy. *Australian Standard* **AS 2856.1**.

STANDARDS AUSTRALIA 2000. Methods for microscopical determination of the reflectance of coal macerals. *Australian Standard* **AS 2856.3**.

STAUB J. R. 1991. Comparisons if central Appalachian Carboniferous coal beds by benches and a raised Holocene peat deposit. *International Journal of Coal Geology* **18**, 45-69.

STEFANOVA. M., MAGNIER C. & VELINOVA D. 1995. Biomarker assemblage of some Miocene-aged Bulgarian lignite lithotypes. *Organic Geochemistry* **23**, 1067-1084.

STEEL T. M. 1961. Appendix 1, Palaeontological Report. *In* Hillwood E. R. ed., *Inkerman – Balaklava Coalfield.* South Australian Department of Mines, Mining Review **112,** pp. 26-34.

STOIAN L. 1999. Palynological analyses and dating of nine samples from the Lochiel coal pit, St. Vincent Basin, South Australia. Primary Industries and Resources South Australia, (unpublished).

STOIAN L. 2003. Palynological analyses and dating of core samples from several drillholes in Bowmans and Lochiel areas, St. Vincent Basin, South Australia. Primary Industries and Resources South Australia, (unpublished).

STOUT A. S. 1992. Aliphatic and aromatic triterpenoid hydrocarbons in a Tertiary angiospermous lignite. *Organic Geochemistry* **18**, 51-66.

STOVER L. E. & PARTRIDGE A. D. 1973. Tertiary and Late Cretaceous spores and pollen from the Gippsland Basin, southeastern Australia. *Proceedings, Royal Society of Victoria* **85**, 237-286.

STUART W. J. 1969. Stratigraphic and structural development of the Tertiary St. Vincent Basin, South Australia. PhD Thesis, University of Adelaide (unpublished).

STYAN W. B. & BUSTIN R. M. 1983. Petrography of some Fraser River delta peat deposits: Coal maceral and microlithotype precursors in temperate-climate peats. *International Journal of Coal Geology* **2**, 321-370.

STYAN W. B. & BUSTIN R. M. 1984. Sedimentology of Fraser River delta deposits: a modern analogue for some deltaic coals. *In* Rahmani R. A. & Flores R. M. eds., *Sedimentology of Coal and Coal-Bearing Sequences*. Special Publication **7**, International Association of Sedimentologists. Blackwell Scientific Publication, Oxford, pp. 241-271.

SUNAY M. & GAINES A. F. 1989. Terrestrial biomarkers in benzene - methanol extracts of Turkish solid fuels. *Fuel* **68**,1264-1269.

TADROS N. Z. 1988. Depositional controls on coal quality of the Hoskissons Coal Member, Black Jack Formation, Gunnedah Basin. *New South Wales Geological Survey Quarterly Notes* **70,** 1-14.

TAYLOR G. H., TEICHMULLER M., DAVIS A., DIESSEL C. F. K., LITTKE R. & ROBERT P. 1998. *Organic Petrology*. Gebruder Borntraeger, Berlin, 704 p.

TEICHMULLER M. 1982. Origin of the petrographic constituents of coal. *In*: Stach E., Mackowsky M.-TH., Teichmuller M., Taylor G. H., Chandra D. & Teichmuller R., *Stach's Textbook of Coal Petrology*. Gebruder Borntraeger, Berlin, pp. 219-294.

TEICHMULLER M. & TEICHMULLER R. 1982. The geological basis of coal formation. *In* Stach E., Mackowsky M.-TH., Teichmuller M., Taylor G. H., Chandra D. and Teichmuller R., *Stach's Textbook of Coal Petrology*. Gebruder Borntraeger, Berlin, pp. 5-218.

TEICHMULLER M. 1989. The genesis of coal from the viewpoint of coal petrology. *International Journal of Coal Geology* **12**, 1-87.

TEN HAVEN H. L., PEAKMAN T. M. & RULLKÖTTER J. 1992a. $\Delta^2$-Triterpenes: Early intermediates in the diagenesis of terrestrial triterpenoids. *Geochimica et Cosmochimica Acta* **56**, 1993-2000.

TEN HAVEN H. L., PEAKMAN T. M. & RULLKÖTTER J. 1992b. Early diagenetic transformation of higher-plant triterpenoids in deep-sea sediments from Baffin Bay. *Geochimica et Cosmochimica Acta* **56**, 2001-2024.

TEN HAVEN H. L., LAFARGUE E. & KOTARBA M. 1993. Oil/oil and oil/source rock correlations in the Carpathian Foredeep and Overthrust, south-east Poland. *Organic Geochemistry* **20**, 935-959.

TISSOLT B. P. & WELTE D. H. 1984. *Petroleum Formation and Occurrence*. Springer-Verlag, Berlin, 699p.

THOMPSON B. P. 1969. Adelaide 1:250,000 map sheet. *South Australian geological atlas series sheet SI 54-9 zones 5&6*, Geological Survey of South Australia, Department of Mines, Adelaide.

TRENDEL J. M., LOHMANN F., KINTZINGER J. P. & ALBRECHT P. 1989. Identification of Des-A-triterpenoid hydrocarbons occurring in surface sediments. *Tetrahedron* **45**, 4457-4470.

VAN AARSSEN B. G. K, COX, H. C., HOOGENDOORN P. & DE LEEUW J. W. 1990a. A cadinene biopolymer in fossil and extant dammar resins as a source for cadinanes and bicadinanes in crude oils from South East Asia. *Geochimica et Cosmochimica Acta* **54**, 3021-3031.

VAN AARSSEN B. G. K., KRUK C., HESSELS J. K. C. & DE LEEUW J. W. 1990b. Cis-cis-trans -bicadinane, a novel member of an uncommon triterpane family isolated from crude oils. *Tetrahedron Letters* **31**, 4645-4648.

VAN AARSSEN B. G. K., HESSELS J. K. C., ABBINK O. A. & DE LEEUW J. W. 1992. The occurrence of polycyclic sesqui-, tri-, and oligoterpenoids derived from a resinous polymeric cadinene in crude oils from southeast Asia. *Geochimica et Cosmochimica Acta* **56**, 1231-1246.

VAN AARSSEN B. G. K., ALEXANDER R. & KAGI R. I. 1996. The origin of Barrow Sub-Basin crude oils: A geochemical correlation using land-plant biomarkers. *APEA Journal* **36(1),** 465- 476.

VENKATESAN M. I., RUTH E, & KAPLAN I. R. 1986. Terpenoid hydrocarbons in Hula peat: Structure and origins. *Geochimica et Cosmochimica Acta* **50**, 1133-1139.

VERHEYEN T. V., PANDOLFO A. G. & JOHNS R. B. 1985. Structural relationships between a brown coal and its kerogen and humic acid fractions. *Organic Geochemistry* **8**, 375-388.

VILLAR H. J., PUTTMANN W. & WOLF M. 1988. Organic geochemistry and petrology of Tertiary coals and carbonaceous shales from Argentina. *Organic Geochemistry* **13**, 1011-1021.

WANG T. G. & SIMONEIT B. R. 1990. Organic geochemistry and coal petrology of Tertiary brown coal in the Zhoujing mine, Baise Basin, South China. *Fuel* **69**, 12-20.

WAPLES D. W. & MACHIHARA T. 1991. *Biomarkers for Geologists: A Practical Guide to the Application of Steranes and Triterpanes in Petroleum Geology.* AAPG Methods in Exploration Series, **9**, 91 p.

WARD C. R. 1984. *Coal Geology and Coal Technology*. Blackwell, Melbourne, 345 p.

WARD C. R. 1986. Review of mineral matter in coal. *Australian Coal Geology* **6**, 87-110

WARD C. R. 1992. Mineral matter in Triassic and Tertiary low rank coals from South Australia. *International Journal of Coal Geology* **20**, 185-208.

WARD C. R. 2002. Analysis and significance of mineral matter in coal seams. *International Journal of Coal Geology* **50**, 135-168.

WARD C. R. & SWAINE D. J. 1995. Minerals and inorganic constituents. *In* Ward C. R., Harrington H. J., Mallett C. W. & Beeston J. W. eds., *Geology of Australian Coal Basins*. Geological Society of Australia, Coal Geology Group, Special Publication **1**, pp. 93-109.

WESTGATE L. M. & ANDERSON T. F. 1984. Isotropic evidence for the origin of sulphur in the Herrin (No. 6) Coal Member of Illinois. *International Journal of Coal Geology* **4**, 1-20.

WESTON R. J., PHILP R. P., SHEPPARD C. M. & WOOLHOUSE A. D. 1989. Sesquiterpanes, diterpanes and other higher terpanes in oils from the Taranaki Basin of New Zealand. *Organic Geochemistry* **14**, 405-421.

WHITE M. E. 1998. *The Greening of Gondwana*. Kangaroo Press, Sydney, 256 p.

WILFORD G. E. & BROWN P. J. 1994. Maps of late Mesozoic – Cenozoic Gondwana break-up; some palaeogeographic implications. *In* Hill R. S. ed., *History of the Australian Vegetation, Cretaceous to Recent*. Cambridge University Press, Cambridge, pp. 5-13.

WILLIAMS E. G. & KEITH M. L. 1963. Relationship between sulphur in coal and the occurrence of marine roof beds. *Economic Geology* **58**, 720-729.

WINKLER E. 1986. Organic geochemical investigations of brown coal lithotypes. A contribution to facies analysis of seam banding in the Helmstedt deposit. *Organic Geochemistry* **10**, 617-624.

WOOLHOUSE A .D., OUNG J. N., PHILP R. P. & WESTON, R. J. 1992. Triterpanes and ring-A degraded triterpanes as biomarkers characteristic of Tertiary oils derived from predominately higher plant sources. *Organic Geochemistry* **18**, 23-31.

WUST R. A. J. & BUSTIN R. M. 2001. Low-ash peat deposits from a dendritic, intermontane basin in the tropics: a new model for good quality coals. *International Journal of Coal Geology* **46**, 179-206.

WUST R. A. J., HAWKE M. I. & BUSTIN R. M. 2001. Comparing maceral ratios from tropical peatlands with assumptions from coal studies: do classic coal petrographic interpretation methods have to be discarded? *International Journal of Coal Geology* **48**, 115-132.

WUST R. A. J., WARD C. R., BUSTIN R. M & HAWKE M. I. 2002. Characterisation and quantification of inorganic constituents of tropical peats and organic-rich deposits from Tasek Bera (Peninsular Malaysia): implications for coals. *International Journal of Coal Geology* **49**, 215-249.

YAGMURLU F. 1986. Depositional environment and coal petrology of Citak (Akhisar) lignite deposits, West Turkey. *International Journal of Coal Geology* **6**, 127-137.

# APPENDICES A to E

# APPENDIX A
# SAMPLING AND TESTING REGISTER

The location of samples and nature of testing undertaken on coals of the Lochiel and Bowmans Deposits is outlined in this Appendix.

Appendix A: Sampling and testing register (sheet 1 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Lochiel | V662 | 29.80 | L391 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V666 | 34.80 | L150 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 34.00 | L365 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 34.90 | L500 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Lochiel | V672 | 35.40 | L501 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 37.00 | L502 | √ | √ | √ | √ | | √ | √ | | | √ | √ | | |
| Lochiel | V672 | 37.65 | L503 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 37.70 | L504 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V672 | 38.15 | L505 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 38.50 | L506 | √ | √ | √ | √ | | √ | √ | | | | | √ | |
| Lochiel | V672 | 38.95 | L507 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 39.15 | L508 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 39.45 | L509 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 39.85 | L510 | √ | √ | √ | √ | | √ | √ | | √ | | | | |
| Lochiel | V672 | 40.30 | L511 | √ | √ | √ | √ | | √ | √ | | | | | √ | |
| Lochiel | V672 | 40.75 | L512 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 41.25 | L513 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Lochiel | V672 | 41.75 | L514 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 42.05 | L515 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 42.20 | L516 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V672 | 42.30 | LP5 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V672 | 42.65 | L517 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V673 | 27.90 | LP6 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V674 | 26.15 | L520 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 26.75 | L521 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 27.40 | L522 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 27.60 | L523 | √ | √ | √ | √ | | | | | | | | | |

Appendix A: Sampling and testing register (sheet 2 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Lochiel | V674 | 28.20 | L524 | √ | √ | √ | √ | | | | | | | | | P |
| Lochiel | V674 | 28.65 | L525 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 29.30 | L526 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 29.80 | L527 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 30.05 | L528 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 30.55 | L529 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V674 | 30.95 | L530 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V674 | 31.35 | L531 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V674 | 31.55 | L532 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V674 | 31.95 | L533 | √ | √ | √ | √ | | √ | √ | | | | | | P |
| Lochiel | V674 | 32.30 | L151 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V674 | 32.40 | L534 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V674 | 32.75 | L535 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | |
| Lochiel | V675 | 27.90 | L152 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V675 | 30.10 | L366 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V675 | 30.60 | L153 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V690 | 45.10 | L154 | √ | √ | √ | √ | √ | √ | √ | | √ | | | √ | |
| Lochiel | V690 | 45.20 | L155 | √ | √ | √ | √ | | √ | √ | | | √ | √ | | |
| Lochiel | V690 | 50.80 | L156 | √ | √ | √ | √ | √ | prox | | | √ | | | √ | |
| Lochiel | V690 | 51.30 | LP2 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V690 | 53.30 | L367 | √ | √ | √ | √ | | √ | √ | | | | | √ | |
| Lochiel | V690 | 54.00 | L368 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V690 | 57.60 | L369 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V690 | 57.90 | LP7 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V690 | 59.60 | L370 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V691 | 54.50 | L371 | √ | √ | √ | √ | | | | | | | | √ | |
| Lochiel | V691 | 54.70 | L372 | √ | √ | √ | √ | | | | | | | | √ | |
| Lochiel | V691 | 55.70 | L373 | √ | √ | √ | √ | | | | | | | | | |

Appendix A: Sample and testing register (sheet 3 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Lochiel | V692 | 18.40 | L374 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V692 | 20.80 | L375 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V692 | 21.00 | LP9 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V694 | 54.30 | L157 | √ | √ | √ | √ | | prox | | | | | | | |
| Lochiel | V695 | 48.00 | L376 | √ | √ | √ | √ | √ | | | | | | | √ | |
| Lochiel | V701 | 51.40 | L377 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V701 | 52.80 | L378 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V701 | 53.20 | L158 | √ | √ | √ | √ | | prox | | | | | | | |
| Lochiel | V703 | 55.10 | L379 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V703 | 63.00 | L380 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V703 | 63.50 | L381 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V703 | 64.00 | L382 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V703 | 64.40 | L383 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V704 | 58.75 | 2 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 59.05 | 3 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 59.20 | 27 | √ | | √ | √ | | √ | √ | √ | | | | | |
| Lochiel | V704 | 59.55 | 4 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 59.80 | 28 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 60.05 | 5 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 60.25 | 29 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 60.50 | 6 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 60.75 | 30 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 61.05 | 7 | √ | √ | √ | | | | | | | | | √ | |
| Lochiel | V704 | 61.20 | 8 | √ | | √ | | | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 63.05 | 9 | √ | √ | √ | | | | | | | | | √ | |
| Lochiel | V704 | 63.15 | 31 | √ | | √ | √ | √ | √ | √ | √ | | √ | √ | | |
| Lochiel | V704 | 63.55 | 10 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 63.70 | 32 | √ | | √ | √ | √ | √ | √ | √ | | | | | |

Appendix A: Sample and testing register (sheet 4 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Lochiel | V704 | 63.94 | 11 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 64.40 | 33 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 64.45 | 12 | √ | √ | √ | | | | | | | | | √ | |
| Lochiel | V704 | 64.80 | 34 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 65.00 | 13 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 65.50 | 14 | √ | √ | √ | | | | | | | | | | |
| Lochiel | V704 | 65.55 | 35 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 65.95 | 36 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 66.05 | 15 | √ | | √ | | | | | | | | | | |
| Lochiel | V704 | 66.40 | 37 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 66.50 | 16 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 67.00 | 17 | √ | √ | √ | | | | | | | | | | |
| Lochiel | V704 | 67.10 | 38 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 67.50 | 18 | √ | | √ | | | | | | | | | | |
| Lochiel | V704 | 67.65 | 39 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 68.00 | 19 | √ | √ | √ | | | | | | | | | | |
| Lochiel | V704 | 68.20 | 40 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 68.55 | 20 | √ | | √ | | | | | | | | | | |
| Lochiel | V704 | 68.65 | 41 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 69.05 | 21 | √ | √ | √ | | | | | | | | | | |
| Lochiel | V704 | 69.35 | 42 | √ | | √ | √ | √ | √ | √ | √ | | √ | √ | | |
| Lochiel | V704 | 69.50 | 22 | √ | √ | √ | | | √ | √ | √ | | | | √ | |
| Lochiel | V704 | 69.65 | 43 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 72.05 | 23 | √ | √ | √ | | | | | | | | | √ | |
| Lochiel | V704 | 72.25 | 44 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Lochiel | V704 | 72.40 | 24 | √ | | √ | | | | | | | | | √ | |
| Lochiel | V704 | 72.65 | 25 | √ | √ | √ | | | | | | | | | | |
| Lochiel | V704 | 72.70 | 45 | √ | | √ | √ | √ | √ | √ | √ | | | | | |

Appendix A: Sample and testing register (sheet 5 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Lochiel | V704 | 72.85 | 26 | √ | √ | √ | | | √ | √ | √ | | | | | |
| Lochiel | V705 | 58.90 | L384 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V705 | 59.50 | L159 | √ | √ | √ | √ | | prox | | | | | | | |
| Lochiel | V705 | 59.60 | LP8 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V706 | 54.35 | L540 | √ | √ | √ | | √ | √ | √ | | | | | | |
| Lochiel | V706 | 55.10 | L541 | √ | √ | √ | | √ | √ | √ | | | | | | |
| Lochiel | V706 | 55.35 | L542 | √ | √ | √ | | √ | √ | √ | | | | | | |
| Lochiel | V706 | 55.65 | L543 | √ | √ | √ | | √ | √ | √ | | | | | | |
| Lochiel | V706 | 55.85 | L544 | √ | √ | √ | | √ | √ | √ | | | √ | √ | √ | |
| Lochiel | V706 | 56.05 | L545 | √ | √ | √ | | √ | √ | √ | | | | | | |
| Lochiel | V706 | 56.60 | L546 | √ | √ | √ | | √ | √ | √ | | | | | | |
| Lochiel | V706 | 57.00 | L547 | √ | √ | √ | | √ | √ | √ | | | | | √ | |
| Lochiel | V706 | 57.20 | L548 | √ | √ | √ | | √ | √ | √ | | √ | | | | |
| Lochiel | V707 | 56.90 | L385 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V707 | 64.00 | L386 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V714 | 53.75 | 47 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Lochiel | V714 | 54.25 | 48 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | P |
| Lochiel | V714 | 54.75 | 49 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 55.25 | 50 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 55.75 | 51 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | |
| Lochiel | V714 | 56.15 | 52 | √ | √ | √ | √ | √ | √ | √ | | | √ | √ | √ | P |
| Lochiel | V714 | 57.05 | 53 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 57.55 | 54 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 58.05 | 55 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | P |
| Lochiel | V714 | 58.45 | 56 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 59.05 | 57 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | |
| Lochiel | V714 | 59.45 | 58 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 60.05 | 59 | √ | √ | √ | √ | √ | √ | √ | | √ | | | √ | |

Appendix A: Sample and testing register (sheet 6 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Lochiel | V714 | 60.55 | 60 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | |
| Lochiel | V714 | 61.05 | 61 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 61.55 | 62 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 62.05 | 63 | √ | √ | √ | √ | √ | √ | √ | | | √ | √ | √ | |
| Lochiel | V714 | 62.60 | 64 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 63.10 | 65 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 63.55 | 66 | √ | √ | √ | √ | √ | √ | √ | | | √ | √ | √ | |
| Lochiel | V714 | 64.00 | 67 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | P |
| Lochiel | V714 | 66.75 | 68 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | P |
| Lochiel | V714 | 67.25 | 69 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | |
| Lochiel | V714 | 67.70 | 70 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 68.25 | 71 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 68.75 | 72 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | P |
| Lochiel | V714 | 69.25 | 73 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V714 | 69.65 | 74 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Lochiel | V715 | 47.70 | L387 | √ | √ | √ | √ | | | | | | | | | |
| Lochiel | V715 | 48.70 | LP3 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V716 | 34.90 | LP4 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V723 | 36.60 | L388 | √ | √ | √ | √ | | √ | √ | | | √ | √ | | |
| Lochiel | V723 | 38.00 | L389 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V723 | 38.60 | L390 | √ | √ | √ | √ | | √ | √ | | | | | | |
| Lochiel | V724 | 33.70 | LP1 | √ | | √ | √ | | | | | | | | | |
| Lochiel | V724 | 38.20 | L160 | √ | √ | √ | √ | | prox | | | | | | | |
| Lochiel | S12 | TL1 | L410 | √ | | √ | √ | | √ | √ | | | | | | |
| Lochiel | S 12 | 0.30 | 101 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 0.70 | 102 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Lochiel | S 12 | 1.00 | 103 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | P/C |
| Lochiel | S 12 | 1.50 | 104 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Lochiel | S 12 | 1.90 | 105 | √ | √ | √ | √ | √ | √ | √ | | | | | | |

Appendix A: Sample and testing register (sheet 7 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Lochiel | S 12 | 2.25 | 106 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 2.65 | 107 | √ | √ | √ | √ | √ | √ | √ | | | | | | C |
| Lochiel | S 12 | 3.10 | 108 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 3.50 | 109 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 3.95 | 110 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 4.65 | 111 | √ | √ | √ | √ | √ | √ | √ | | √ | | | | P |
| Lochiel | S 12 | 5.05 | 112 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 5.40 | 113 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 5.85 | 114 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Lochiel | S 12 | 6.30 | 115 | √ | √ | √ | | | √ | √ | | | | | | P |
| Bowmans | B5 | 69.90 | 69.9 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 70.50 | 70.5 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 71.00 | 71 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 71.70 | 71.7 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 72.10 | 72.1 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B5 | 72.70 | 72.7 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 73.50 | 73.5 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B5 | 73.90 | 73.9 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 74.30 | 74.3 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 74.90 | 74.9 | √ | √ | √ | √ | √ | √ | √ | | √ | | | | |
| Bowmans | B5 | 75.40 | 75.4 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 75.90 | L600 | √ | √ | √ | √ | √ | √ | √ | | √ | | | | |
| Bowmans | B5 | 76.40 | 76.4 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 76.90 | L601 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B5 | 77.60 | 77.6 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 78.10 | L602 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B5 | 78.65 | 78.65 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 81.50 | 81.5 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |

Appendix A: Sample and testing register (sheet 8 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Bowmans | B5 | 81.95 | 81.95 | √ | | √ | √ | √ | √ | √ | | | | | | P |
| Bowmans | B5 | 82.50 | 82.5 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 83.55 | 83.55 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 83.95 | L603 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B5 | 84.00 | 84 | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | | |
| Bowmans | B5 | 84.50 | 84.5 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 84.95 | 84.95 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B5 | 85.50 | 85.5 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 85.95 | 85.95 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 86.50 | 86.5 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B5 | 86.95 | 86.95 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 88.00 | 88 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 88.50 | L604 | √ | √ | √ | √ | √ | √ | √ | | √ | | | | P |
| Bowmans | B5 | 89.00 | 89 | √ | | √ | √ | √ | √ | √ | √ | | | | | |
| Bowmans | B5 | 90.00 | 90 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B5 | 91.00 | 91 | √ | | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 63.05 | 2 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 63.40 | 3 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B 28 | 63.80 | 4 | √ | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | P |
| Bowmans | B 28 | 64.15 | 5 | √ | | | | | | | | | | | | P |
| Bowmans | B 28 | 64.30 | 6 | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | |
| Bowmans | B 28 | 64.40 | 7 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 64.80 | 8 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 65.30 | 9 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 65.70 | 10 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 66.15 | 11 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 66.50 | 12 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 67.00 | L610 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | √ | |

Appendix A: Sample and testing register (sheet 9 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Bowmans | B 28 | 67.40 | 14 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 68.00 | L611 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Bowmans | B 28 | 68.50 | 16 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 69.00 | 17 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B 28 | 69.45 | 18 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 70.10 | L612 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | | |
| Bowmans | B 28 | 70.45 | 20 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 70.70 | 21 | √ | | | | | | | | | | | | P |
| Bowmans | B 28 | 71.00 | 22 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 71.40 | 23 | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | |
| Bowmans | B 28 | 72.00 | 24 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 72.40 | 25 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | P |
| Bowmans | B 28 | 72.70 | 26 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 73.60 | 27 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 74.20 | 28 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B28 | 74.50 | L613 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | | |
| Bowmans | B 28 | 74.80 | 30 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 75.50 | L614 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B 28 | 75.55 | 32 | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | √ | |
| Bowmans | B 28 | 77.20 | 34 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 77.50 | L615 | √ | √ | √ | √ | √ | √ | √ | | | | | | P |
| Bowmans | B 28 | 78.20 | 36 | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | √ | |
| Bowmans | B 28 | 78.60 | 37 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 79.02 | 38 | √ | √ | √ | √ | √ | √ | √ | √ | √ | | | √ | |
| Bowmans | B 28 | 79.40 | 39 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 80.00 | 40 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 80.50 | L616 | √ | √ | √ | √ | √ | √ | √ | | | √ | √ | | |
| Bowmans | B 28 | 81.00 | 42 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |

Appendix A: Sample and testing register (sheet 10 of 10)

| Sample Location and Identification | | | | Testing Undertaken - Current Research Project | | | | | | | | | | | Co-operative Research | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lithotype | | Maceral | | | Chemical | | | C.I. | Biomarker | | | |
| Deposit | Hole | Depth | Name | Desc-ription | Photo-graph | Grain Prep | Desc-cription | Point Count | Suite A | Suite B | Quartz | | Yield | GC-MS | Mineral Matter | Palaeo-botany |
| Bowmans | B 28 | 81.45 | 43 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 81.90 | L617 | √ | √ | √ | √ | √ | √ | √ | | | | | √ | |
| Bowmans | B 28 | 82.40 | 45 | √ | √ | √ | √ | √ | √ | √ | | √ | | | √ | |
| Bowmans | B 28 | 82.80 | 46 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 83.50 | 47 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B 28 | 84.00 | 48 | √ | √ | √ | √ | √ | √ | √ | √ | | | | | |
| Bowmans | B 28 | 84.40 | L618 | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | | P |
| Bowmans | B 28 | 84.70 | 50 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 85.85 | 53 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 86.10 | 54 | √ | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | |
| Bowmans | B 28 | 86.40 | 55 | √ | | | | | | | | | | | | P |
| Bowmans | B 28 | 89.40 | 56 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |
| Bowmans | B 28 | 90.30 | 57 | √ | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | |
| Bowmans | B 28 | 91.60 | 59 | √ | √ | √ | √ | √ | √ | √ | | | | | | |
| Bowmans | B 28 | 92.70 | 60 | √ | √ | √ | √ | √ | √ | √ | √ | | √ | √ | √ | P |
| Bowmans | B 28 | 94.10 | 61 | √ | √ | √ | √ | √ | √ | √ | √ | | | | √ | |

Key to Appendix A:

Suite A chemical testing includes proximate analysis (ash, volatile matter, moisture, fixed carbon), total sulphur and ash analysis ($Fe_2O_3$, $Al_2O_3$, $SiO_2$, MgO, CaO, $K_2O$, $Na_2O$, $SO_3$, $TiO_2$).

Suite B chemical testing includes ultimate analysis (C, H, N, O, S), forms of sulphur (organic, pyritic, sulphate), inorganics (Na, Cl) and acid soluble inorganics (Fe, Al, Si, Mg, Ca, K).

Quartz indicates a chemically determined quartz value

C.I. = colour index

Co-operative research included mineral investigation (SEM/EDS, XRD) and palaeobotanical studies (P = palynology, C = cuticular analysis).

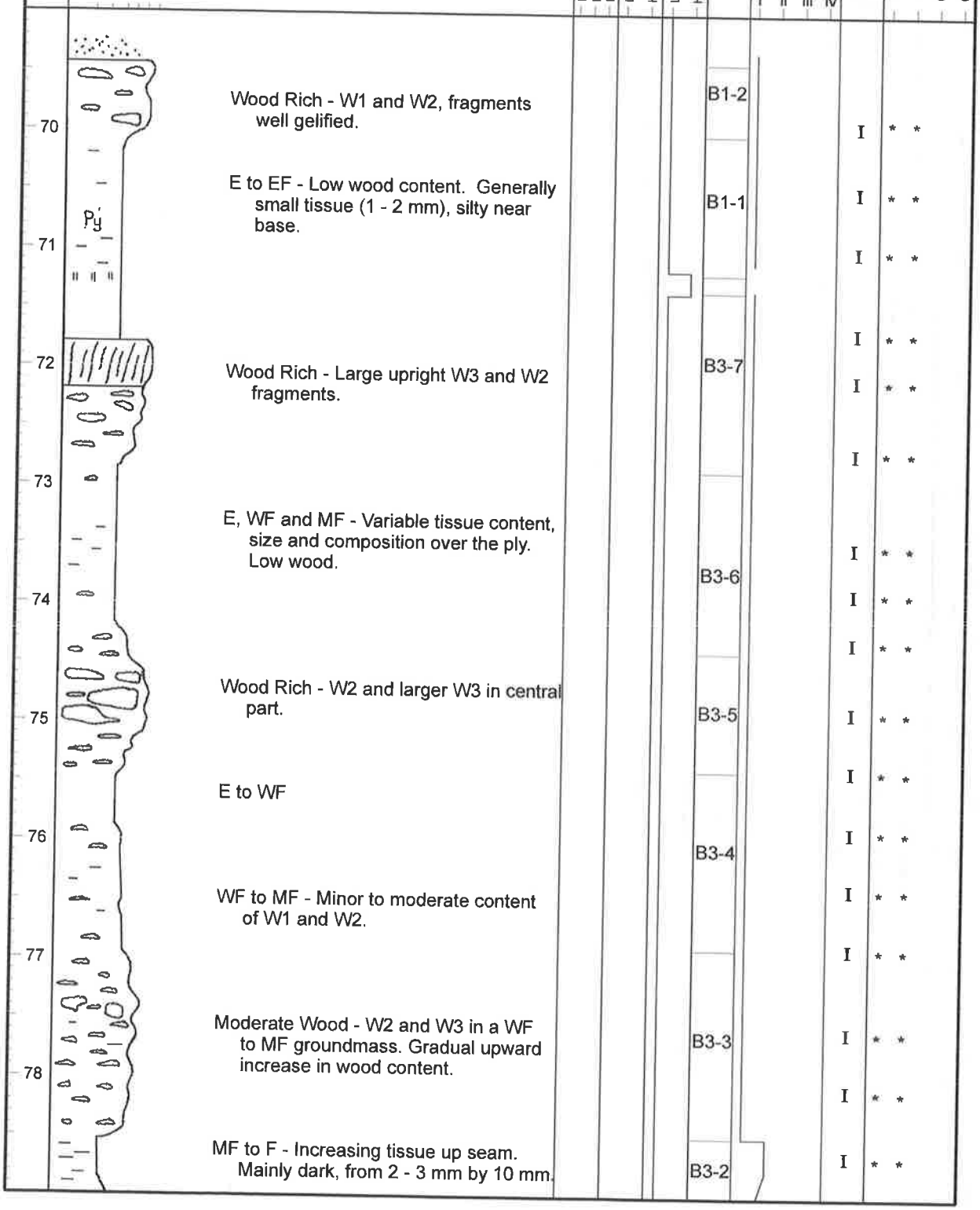
# APPENDIX B
# BOREHOLE LITHOTYPE LOGS

Lithotype information gathered during the course of this project from coals in the Lochiel and Bowmans Deposit is presented in this Appendix as a suite of graphic and descriptive 1:50 scale borehole lithotype logs. The lithotype logging methodology described in Chapter 3 and criteria used for lithotype evaluation are elaborated in Chapter 5.

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE B5 | Sheet 1 of 3 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE B5 | Sheet 2 of 3 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I, II, III, IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 80 | | MF - Silty. | | | | B1-2 | | | | | | |
| 81 | | Wood Rich - W2 and W3. Sandy in the immediate vicinity of wood fragments. | | | | | | I | * | * | | |
| 82 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| | | | | | | C5 | | | | | | |
| 83 | | E to WF - Low tissue, low wood. | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 84 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 85 | | | | | | | | I | * | * | | |
| | | Wood Rich - W3 and W2. Sharp ply boundaries. | | | | C4 | | I | * | * | | |
| 86 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 87 | | | | | | | | I | * | * | | |
| | | WF to E - Tissue varies in size, abundance and composition. Low wood. | | | | C3 | | I | | | | |
| 88 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| | | | | | | | | | * | * | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE B5 | Sheet 3 of 3 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG<br>Low Wood / Wood Rich<br>Texture / Particle Size<br>VE VF F Sm Md Lg | DESCRIPTION | COLOUR<br>Light Medium Dark | GELE-FICATION<br>Low High | MINERAL MATTER<br>Low High | PLY | FACIES<br>I II III IV | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 90 | | Wood Rich | | | | C3 | | | | | | |
| | | | | | | C2 | | I | * | * | | |
| | | | | | | C1 | | | | | | |
| 91 | | VE to E - Well gelified. | | | | | | I | * | * | | |
| 92 | | | | | | | | | | | | |
| 93 | | | | | | | | | | | | |
| 94 | | | | | | | | | | | | |
| 95 | | | | | | | | | | | | |
| 96 | | | | | | | | | | | | |
| 97 | | | | | | | | | | | | |
| 98 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE B28 | Sheet 1 of 4 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F M C VC) | DESCRIPTION | COLOUR: Light / Medium / Dark | GELE-FICATION: Low / High | MINERAL MATTER: Low / High | PLY | FACIES: I II III IV | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 63 | | WF to MF - Some W1 and W2. Tissue of various sizes and composition. Light band at base of ply. | | | | B1-4 | I | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 64 | | | | | | | | I | * | * | * | |
| | LIGHT | | | | | | | I | * | * | * | |
| | | | | | | | | I | * | * | | |
| 65 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 66 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| | | | | | | B1-3 | | I | * | * | * | * |
| 67 | | WF to MF - Dark, low wood. Tissue characteristics vary, but mainly small (<0.5 mm by 2 - 10 mm) and dark. | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 68 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 69 | | | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| 70 | | | | | | | | I | * | * | * | |
| | | | | | | | | I | * | * | | |
| 71 | | | | | | | | I | * | * | | |
| | | Wood Rich - W1, W2 and W3 in MF groundmass. | | | | B1-2 | | I | * | * | * | |
| | | | | | | | | | * | * | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE B28 | Sheet 2 of 4 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F M C VC) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 73 | | Moderate Wood - Mainly thin and elongate W1 and W2 fragments, within a WF groundmass. | | | | B1-3 | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| | | MF - Light brown, greenish and black tissue. Locally elongate W1 rich. | | | | | | I | * | * | | |
| 74 | | | | | | | | I | * | * | | |
| | | | | | | B1-1 | | I | * | * | * | |
| | | E (to WF) - Sandy, minor W1. | | | | | | I | * | * | | |
| 75 | | E to VE - Well gelified. | | | | | | I | * | * | | |
| 76 | | | | | | | | | | | | |
| 77 | | E to WF - Dark, minor W1. | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | | |
| | | | | | | B3-7 | | | | | | |
| 78 | | | | | | | | I | * | * | | |
| | | Moderate Wood - Small W1 and W2 within a WF groundmass. | | | | | | I | * | * | | |
| 79 | | | | | | | | I | * | * | | |
| | | WF - Low wood, variable tissue composition. | | | | B3-6 | | I | * | * | | |
| | | | | | | B3-5 | | | | | | |
| 80 | | Moderate Wood - Elongate W2, moderate tissue content. | | | | | | I | * | * | | |
| | | | | | | | | I | * | * | * | |
| | | MF to WF - Variable tissue size and composition, although generally dark. Low wood content. | | | | B3-4 | | I | * | * | | |
| 81 | | | | | | | | I | * | * | | |
| | | | | | | B3-3 | | I | * | * | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE B28 | Sheet 3 of 4 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F E Sm Md Lg) | DESCRIPTION | COLOUR: Light | COLOUR: Medium | COLOUR: Dark | GELE-FICATION: Low | GELE-FICATION: High | MINERAL MATTER: Low | MINERAL MATTER: High | PLY | FACIES: I II III IV | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 83 | | Wood Rich - W1, W2 and large W3. Typically MF groundmass, although variable in concentration. | | | | | | | | B3-3 | | I | * | * | | |
| | | | | | | | | | | | | I | * | * | | |
| | | | | | | | | | | | | I | | | | |
| | | | | | | | | | | | | I | * | * | | |
| 84 | | | | | | | | | | | | I | * | * | | |
| | | F - Well gelified, silty. Leaf fragments common and tissue particles generally < 1 mm. Low wood. | | | | | | | | B3-2 | | I | * | * | * | |
| 85 | | | | | | | | | | | | I | * | * | | |
| | | F / Wood Rich - Abundant elongate W1 in a F groundmass. Tissue mainly dark and ranging in size from < 1 mm to 5 - 10 mm. | | | | | | | | B3-1 | | I | * | * | | |
| 86 | | | | | | | | | | | | I | * | * | * | |
| | | F / Wood Poor - F groundmass consisting mainly of tissue 1 - 2 mm in size. Significant proportion of light particles. | | | | | | | | | | | | | | |
| 87 | | | | | | | | | | | | | | | | |
| 88 | | | | | | | | | | | | | | | | |
| 89 | | WF - Low wood content, sandy at base. | | | | | | | | C? | | I | * | * | | |
| 90 | | | | | | | | | | | | I | * | * | * | |
| 91 | | | | | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE B28 | Sheet 4 of 4 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG<br>Low Wood / Wood Rich<br>Texture / Particle Size<br>VE VF F Sn Md Lg | DESCRIPTION | COLOUR<br>Light Medium Dark | GELE-FICATION<br>Low High | MINERAL MATTER<br>Low High | PLY | FACIES<br>I II III IV | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 93 | | E to WF - Low wood. | | | | C? | | I | * | * | * | |
| 94 | | | | | | | | I | * | * | | |
| 95 | | | | | | | | | | | | |
| | | | | | | | | | * | | | |
| 96 | | | | | | | | | | | | |
| 97 | | | | | | | | | | | | |
| 98 | | | | | | | | | | | | |
| 99 | | | | | | | | | | | | |
| 100 | | | | | | | | | | | | |
| 101 | | | | | | | | | | | | |

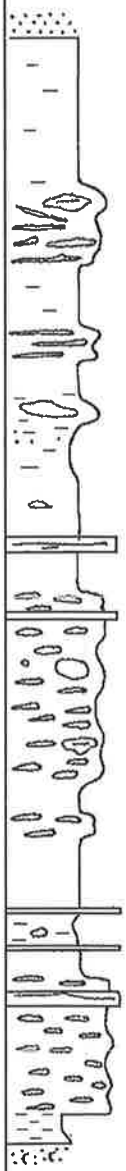
# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V320 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** ??.??.1981 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 950.70 **N:** 6 213 535.10 **Elev:** 17.20
**CORE LOGGED:** 15.03.1990 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F E Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I, II, III, IV) | INTERVAL | Petrology | Biomarker | Chemical | Other




E (to WF) - Dark, low wood. Light and tissue of variable size, (< 2 mm).

Wood Rich - Mainly very elongate W2, (2 - 5 mm thick by > 60 mm).

WF - Variable tissue size and composition, commonly < 1 mm.
Moderate Wood - Elongate W2, showing and upward increase in abundance.

WF - Variable tissue size and composition. Occasional W2 and W3. Sandy near centre.

Wood Rich - Mainly elongate W2 (1 - 2 mm thick), showing increasing elongation up seam. WF groundmass light tissue common (< 2 mm).

WF - Variable tissue concentration and composition. Occasional W3.

Wood Rich - Mainly elongate W2, (1 - 2 mm thick by 5 - 10 mm).

F - Abundant light platy tissue mostly between 5 - 10 mm.

PLY: B3-7, B3-6, B3-5, B3-4, B3-3, B3-2

INTERVAL: SPLIT CORE

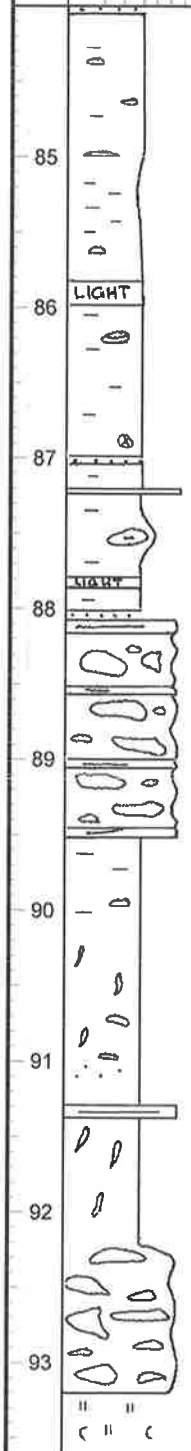
# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V320 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** ??.??.1981 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 950.70 **N:** 6 213 535.10 **Elev:** 17.20
**CORE LOGGED:** 15.03.1990 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F M C; Particle Size: Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other




E to WF - Dark, low wood and generally low tissue.

MF - Tissue of variable size and composition.

Light - WF, tissue mainly light (< 1 mm) in light groundmass.

E to WF - Tissue of variable size and composition. Low wood.

C5

E to WF - Mainly dark, except for distinct light band. Occasional W3.

Wood Rich - Abundant W3 in WF groundmass.

C4

E (to WF) - Generally low tissue and of variable composition. Vertical, well gelified particles throughout, low wood. Sandy near centre.

C3

Wood Rich - Mainly W3 with occasional elongate W2. WF groundmass

C2

SPLIT CORE

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V321 | Sheet 1 of 3 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F M C; Particle Size: Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I, II, III, IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

67 — LIGHT

Wood Rich - Abundant elongate W2, (2 mm thick by 5 - 20 mm). Light and silty bands in lower portion.

68

Moderate Wood - Generally small elongate W2 (0.5 - 2 mm thick by 5 - 10 mm). Contains thin light band. Sandy near base.

B1-2 + B1-1

69 — LIGHT

70

Moderate Wood - Small W2. Dark WF groundmass.

B3-7

71

WF - Occasional W2 and W3 fragments (especially near base). Light and dark tissue.

B3-6

72 — LIGHT

73

Wood Rich - Mainly W3, with some W2. Light band near top.

B3-5

74

MF - Yellow green, leafy fragments common. Some W2 and W3 near base.

B3-4

75 — LIGHT

E - Light and dark bands.

B3-3

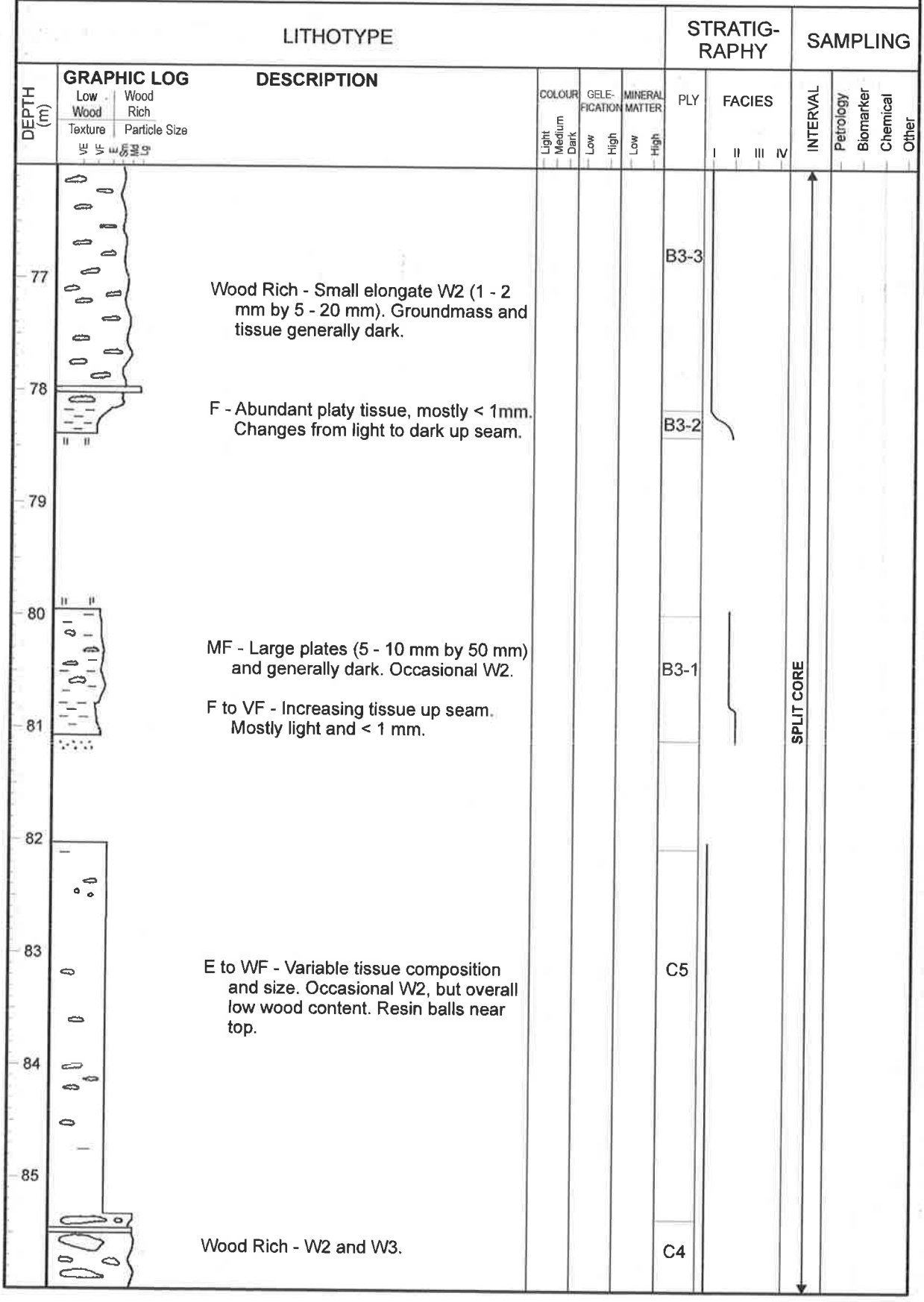
Moderate Wood - Mainly W2.

SPLIT CORE

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V321 | Sheet 2 of 3 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS



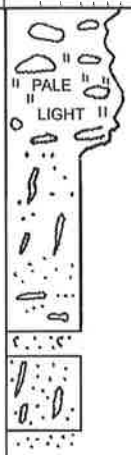
# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V321 | Sheet 3 of 3 |
|---|---|---|

**HOLE DRILLED:** 20.05.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 245 992.83 **N:** 6 213 985.40 **Elev:** 16.15
**CORE LOGGED:** 20.05.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF E Sm Md Lg; Particle Size) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other




87
88
89
90
91
92
93
94
95

Wood Rich - Mainly W3 with some W2. Pale and light bands with abundant resin and leaf fragments. Silty.

E - Light to medium brown. Sandy throughout. Near vertical well gelified particles common, (2 - 4 mm diam.).

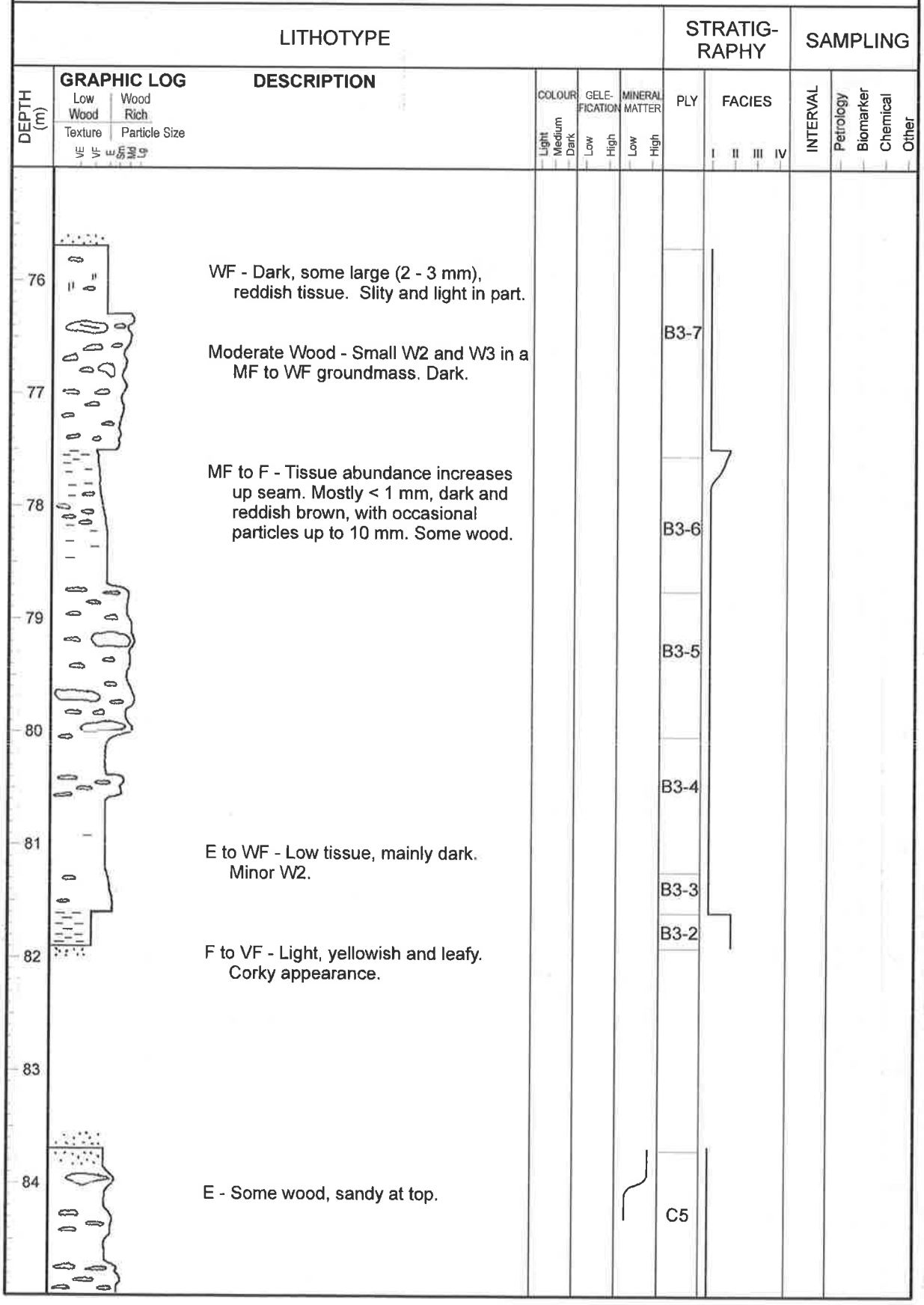
PLY: C4, C3

INTERVAL: SPLIT CORE

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V336 | Sheet 1 of 2 |
|---|---|---|

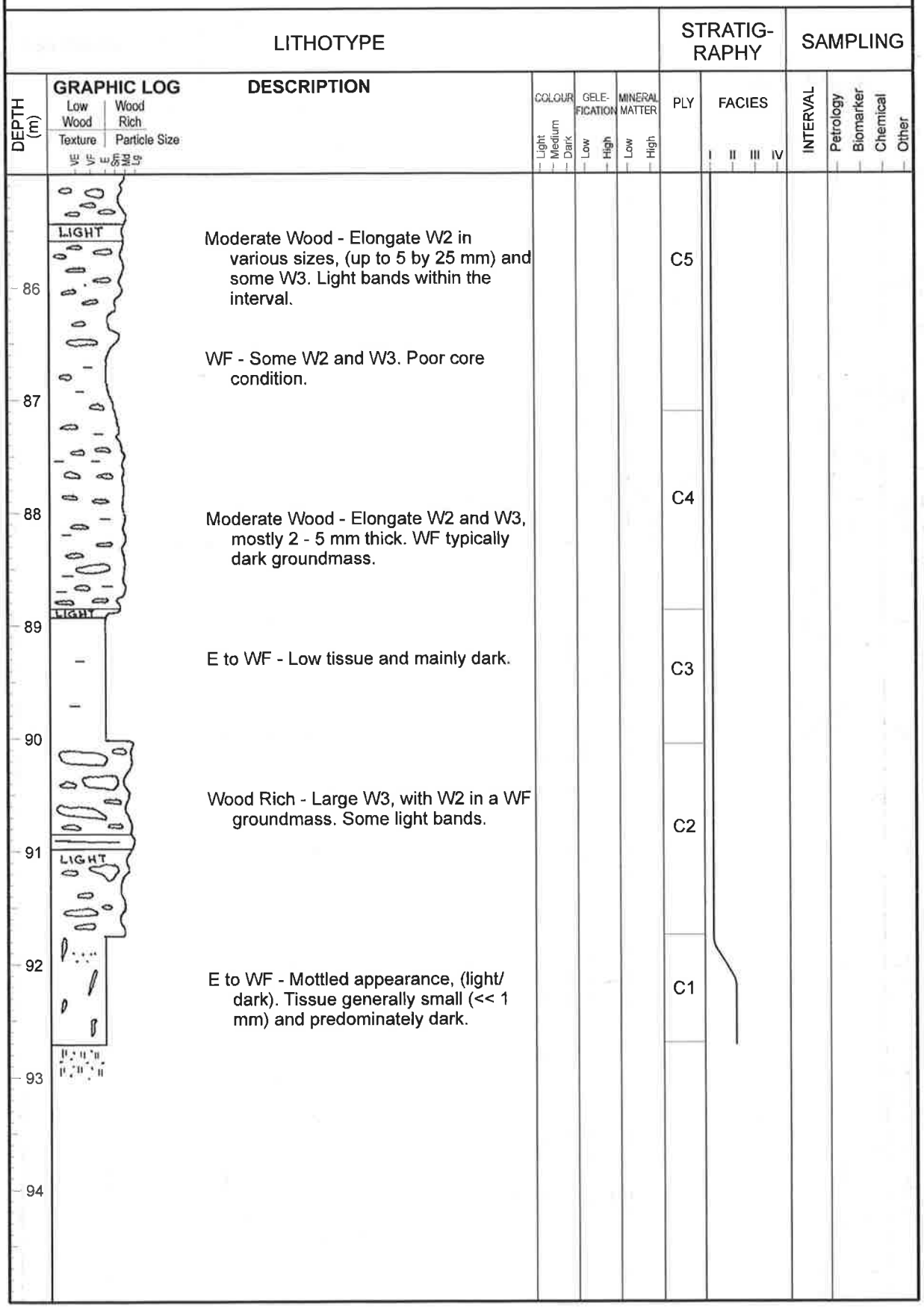
**HOLE DRILLED:** ??.??.1981 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 246 572.00 **N:** 6 212 722.80 **Elev:** 20.60
**CORE LOGGED:** 15.03.1990 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V336 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** ??.??.1981 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 246 572.00 **N:** 6 212 722.80 **Elev:** 20.60
**CORE LOGGED:** 15.03.1990 **CORE DIAMETER:** 100mm **DEPOSIT:** BOWMANS



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V634 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 29.11.1984 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 480.00 **N:** 6 245 930.00 **Elev:** 79.00
**CORE LOGGED:** 29.11.1984 **CORE DIAMETER:** 890mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG<br>Low Wood / Wood Rich<br>Texture / Particle Size<br>VE VF F Sm Md Lg | DESCRIPTION | COLOUR<br>Light Medium Dark | GELE-FICATION<br>Low High | MINERAL MATTER<br>Low High | PLY | FACIES<br>I II III IV | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 36 | | | | | | | | | | | | |
| 37 | | VE - Dark, highly gelified, slightly silty. | | | | F5 | | | | | | |
| | | Fractured Coal - Friable, dark, silty inclusions.<br>Brecciated Coal - Small, hard, dark fragments. | | | | F4 | | | | | | |
| 38 | | | | | | F3 | | | | | | |
| 39 | | F - Platy, low wood. Locally rich in charcoal. Gradational upper and lower boundaries. | | | | F2 | | | | | | |
| 40 | | E - Fine sand laminae near base. | | | | | | | | | | |
| | | | | | | F1 | | | | | | |
| 41 | | | | | | | | | | | | |
| 42 | LIGHT | Light Coal - E, hard.<br>E - Medium brown, low wood. | | | | G6 (N) | | | | | | |
| | | VF - Dark, sharp contacts. | | | | G5 | | | | | | |
| 43 | | E - Low wood. Two horizons of hard, gravel sized coal particles. | | | | | | | | | | |
| 44 | | | | | | G4 | | | | | | |
| | | E - Low wood. | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V634 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 29.11.1984 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 480.00 **N:** 6 245 930.00 **Elev:** 79.00
**CORE LOGGED:** 29.11.1984 **CORE DIAMETER:** 890mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF, F, Sm, Md, Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I, II, III, IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 46 | | MF | | | | G4 | | | | | | |
| | | E - Moderate wood, W1 and W2. | | | | G3 | | | | | | |
| 47 | | MF | | | | | | | | | | |
| | | E - Moderate wood, mainly elongate W2 and W1. | | | | | | | | | | |
| 48 | | | | | | G2 | | | | | | |
| 49 | | E - Medium to dark. Some W1 and W2 Vertical well gelified inclusions. Well gelified at base. | | | | G1 | | | | | | |
| 50 | | | | | | | | | | | | |
| 51 | | | | | | | | | | | | |
| 52 | | E - Bioturbated at top, low wood. | | | | H2 | | | | | | |
| 53 | | Wood Rich - Large W3 common. | | | | H1b | | | | | | |
| | | Wood Rich - Sandy coal. Fine sand disseminated and in thin irregular beds. | | | | H1a | | | | | | |
| 54 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V661 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 20.01.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 998.72 **N:** 6 241 000.04 **Elev:** 85.01
**CORE LOGGED:** 20.01.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | STRATIG-RAPHY | | SAMPLING | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F M Sm Mid Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology / Biomarker / Chemical / Other |
| 27 | | E - Generally low wood. | | | | G6 (N) | | | |
| 28 | | | | | | | | | |
| 29 | | F to VF - Dark, platy, very low wood. | | | | G5 | | | |
| 30 | | | | | | | | | |
| 31 | | Brecciated Coal - Gravel sized particles. | | | | G4 (?) | | | |
| 32 | | Fractured Coal - Wood rich except near top, mainly W3. | | | | | | | |
| 33 | | | | | | | | | |
| 34 | | | | | | | | | |
| 35 | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V662 | Sheet 1 of 2 |
|---|---|---|

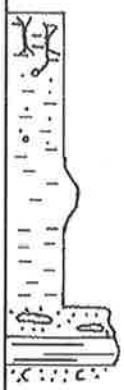
**HOLE DRILLED:** 21.01.1986 **MOISTURE CONTENT:** Air Dried **LOCATION:** **E:** 240 861.75 **N:** 6 240 500.83 **Elev:** 82.03
**CORE LOGGED:** 28.02.1989 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F E Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 18 | | W3 - Very fibrous. | | | | | | SPLIT CORE | | | | |
| 19 | | E - Moderate wood, (spiky W1 and some W3 fragments). Sandy near base. | | | | | | | | | | |
| 20 | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | |
| 24 | | E - Moderate wood, (W1 and elongate W2).<br>E - Minor sand.<br>Wood Rich - W2 and W3, minor sand.<br>E - Some W1 and W2, sandy.<br>Light Coal | | | | | | SPLIT CORE | | | | |
| 25 | LIGHT | | | | | G6 (N) | | | | | | |
| 26 | | E - Dark, moderate sand, low wood.<br>E - Some W1 and rare W3, sandy especially near base. | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V662 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 21.01.1986 **MOISTURE CONTENT:** Air Dried **LOCATION:** **E:** 240 861.75 **N:** 6 240 500.83 **Elev:** 82.03
**CORE LOGGED:** 28.02.1989 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF, F, Sm, Md, Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I, II, III, IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 28 |  | Weathered Coal. | | | | | | SPLIT CORE | | | | |
| 29 | | VF - Dark, variable charcoal. Minor sand near top. | | | | G5 | | | | | | |
| 30 | | Wood Rich - Mainly W3, fine disseminated sand. | | | | G4 (?) | | | | | | |
| 31 | | | | | | | | | | | | |
| 32 | | | | | | | | | | | | |
| 33 | | | | | | | | | | | | |
| 34 | | | | | | | | | | | | |
| 35 | | | | | | | | | | | | |
| 36 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V670 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 27.01.1986 **MOISTURE CONTENT:** Air Dried **LOCATION:** **E:** 241 250.81 **N:** 6 241 489.26 **Elev:** 87.83
**CORE LOGGED:** 24.02.1989 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F Sm Mid Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

32 — LIGHT

E - Light bands in lower portion.

E - Small broken wood fragments, (W1) in part

33

G6 (N)

F - Platy (2 - 5 mm), low charcoal.

34

Slightly Weathered Coal - Some wood fragments,(< 20 mm).

E to WF - Low wood.

35

F to VF - Dark, very low wood, locally charcoal rich.

G5

36

E - Medium to dark brown.

G4

Wood Rich - Elongate W2 and W3. Low tissue.

37

WF to MF - Some elongate W2 and W3 in central portion. Sandy near base.

G3

38

SPLIT CORE

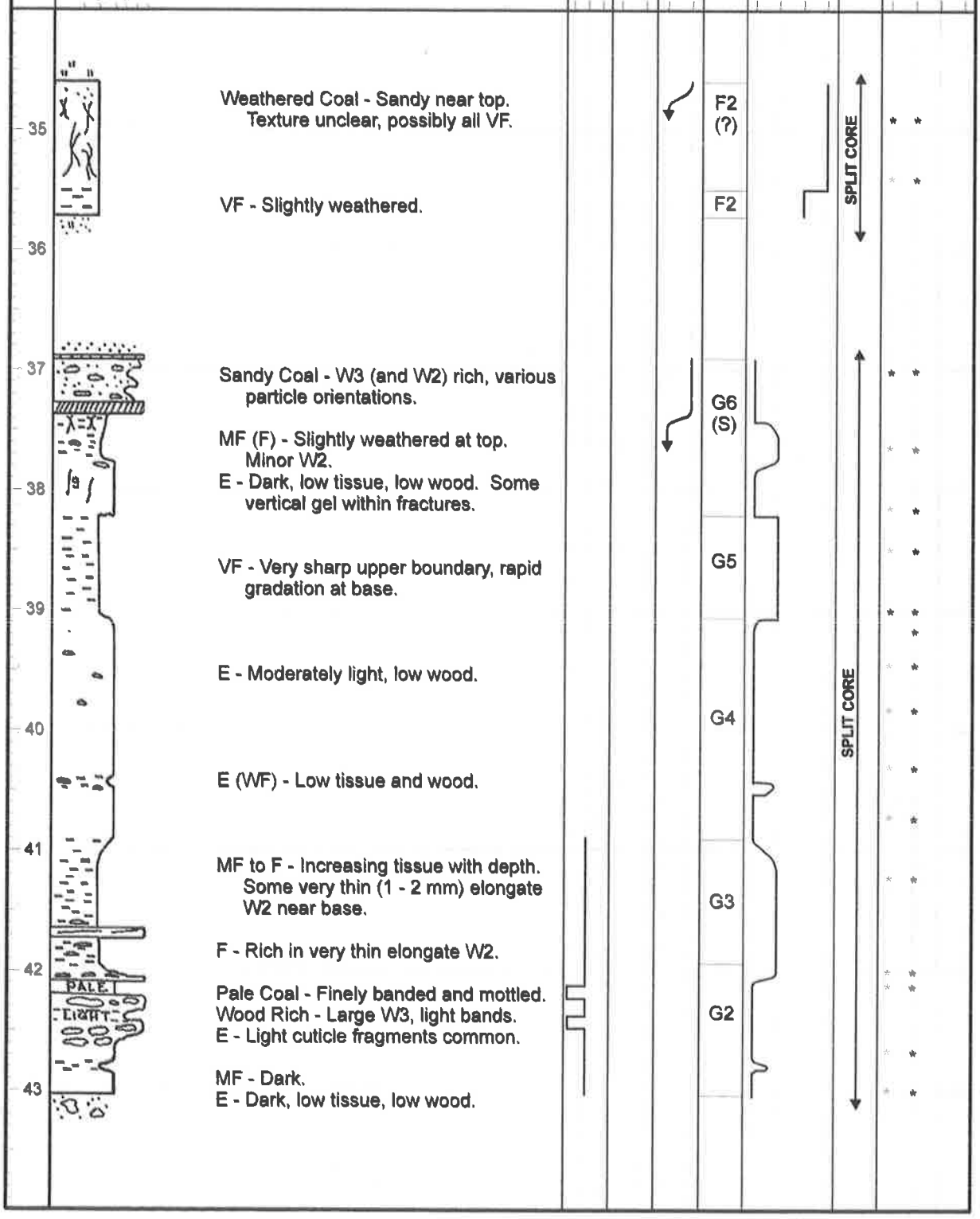
39

40

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V672 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 28.01.1986 **MOISTURE CONTENT:** Air Dried **LOCATION:** **E:** 241 000.04 **N:** 6 242 500.18 **Elev:** 83.27
**CORE LOGGED:** 02.03.1989 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V673 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 29.01.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** E: 242 910.81 N: 6 242 740.32 **Elev:** 83.83
**CORE LOGGED:** 29.01.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F M C VC) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I, II, III, IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

21

E - Sandy near top, becoming silty with depth. Low wood content.

22

G6 (S)

E - Thin sand laminations throughout. High sand content immediately below W3.

23

24

Wood Rich - Mainly W3.

G4

E to WF - Low wood.

25

26

MF to F - Gradational base and top.

G3

27

VE - Dark, relatively soft, low groundmass tissue. Breaks with conchoidal fracture.

G1

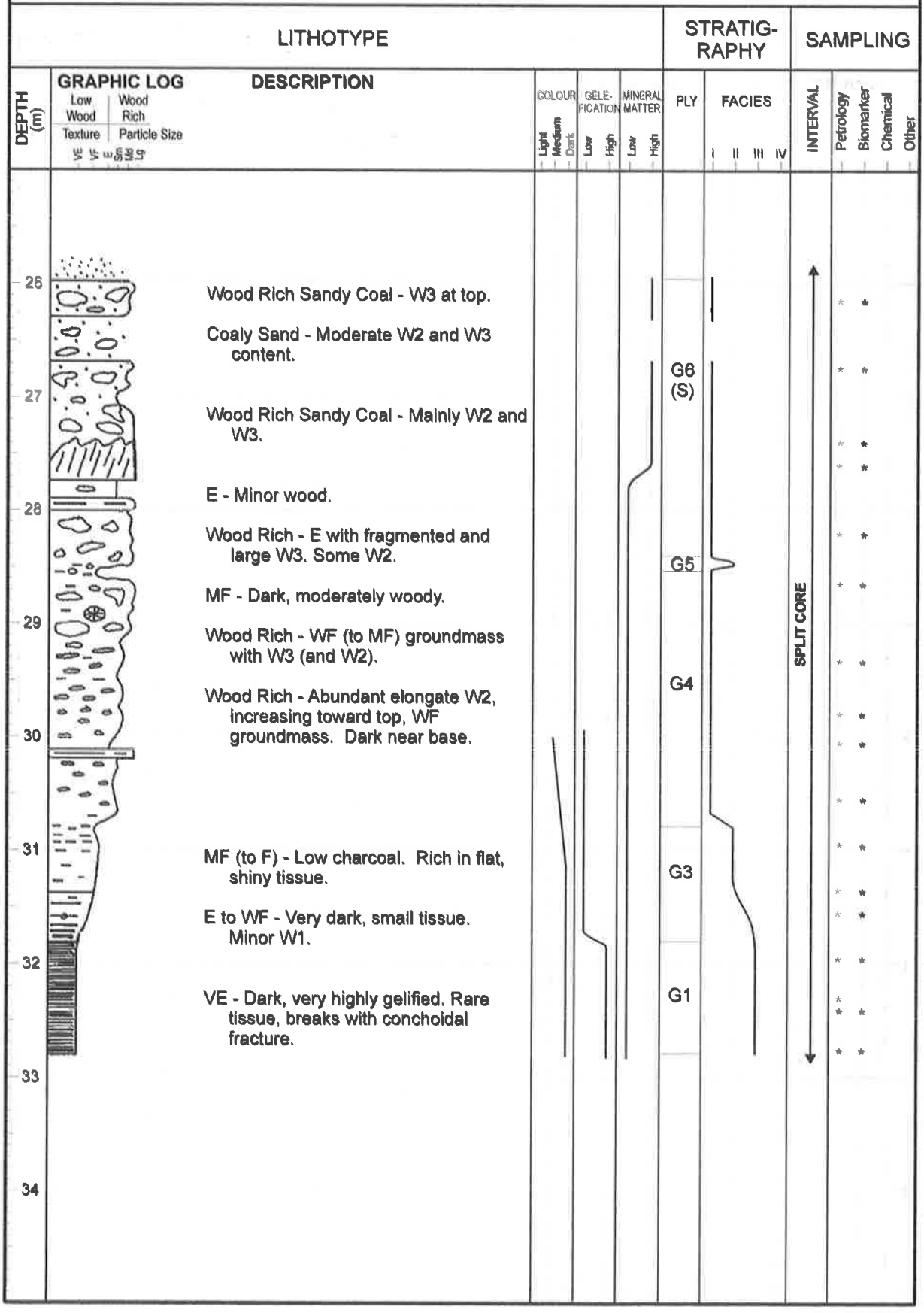
28

29

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V674 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 30.01.1986 **MOISTURE CONTENT:** Air Dried **LOCATION:** E: 242 410.85 N: 6 242 499.54 **Elev:** 86.55
**CORE LOGGED:** 02.03.1989 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V675 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 31.01.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 243 001.39 **N:** 6 243 499.28 **Elev:** 86.23
**CORE LOGGED:** 31.01.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VE VF E Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

27
28
29
30
31
32
33
34
35

Weathered Coal - Dark and friable.
Original groundmass texture unclear.

VE - Very dark, soft and highly gelified.
Breaks with conchoidal fracture.
Grades rapidly to E at top.

Brecciated Coal - Consists of small (< 5 mm), hard fragments. Friable.

E - Moderate content of W2 and W3.

G6 (S)

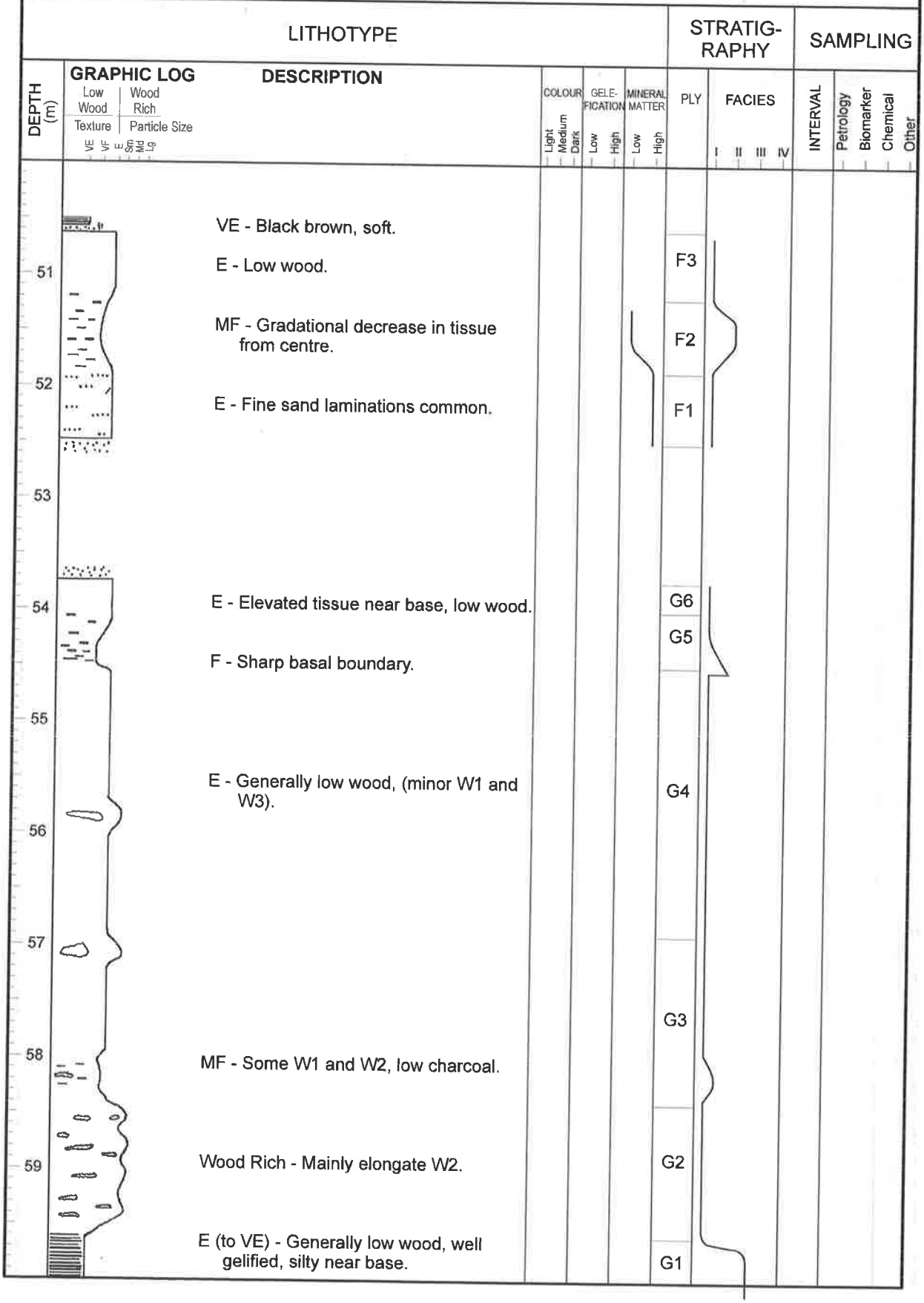
G5 ?

G4 ?

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V679 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 04.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 749.88 **N:** 6 246 500.26 **Elev:** 93.79
**CORE LOGGED:** 04.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V679 | Sheet 2 of 2 |
|---|---|---|

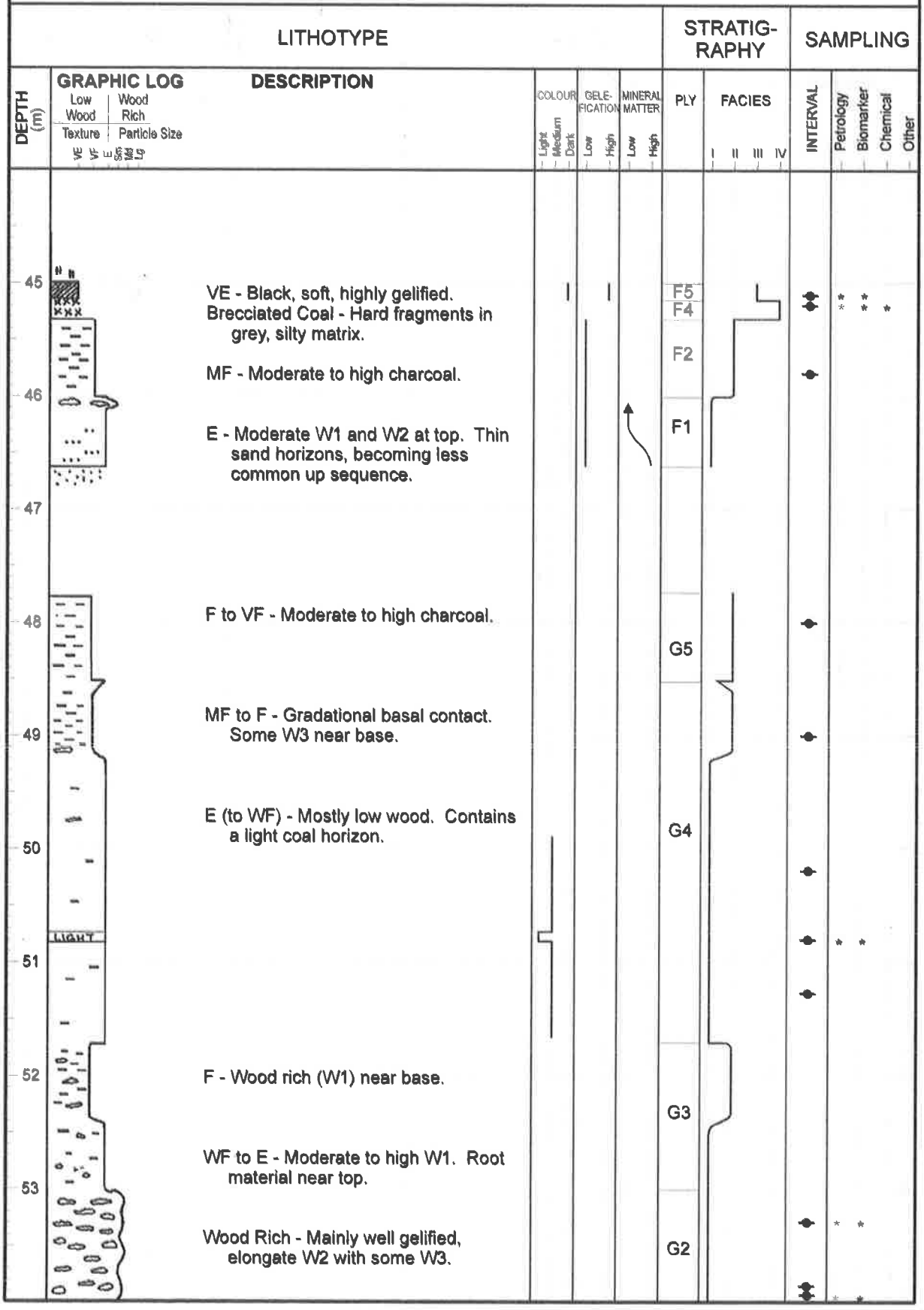
**HOLE DRILLED:** 04.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 749.88 **N:** 6 246 500.26 **Elev:** 93.79
**CORE LOGGED:** 04.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 61 | | | | | | | | | | | | |
| 62 | | | | | | | | | | | | |
| 63 | | E - Boiturbated near top and sandy in part. Minor wood. | | | | H2 | | | | | | |
| | | Wood Rich - Predominately W3. Silty in part. | | | | H1a | | | | | | |
| 64 | | | | | | H2a | | | | | | |
| | | Wood Rich Silty Coal. | | | | | | | | | | |
| 65 | | | | | | | | | | | | |
| 66 | | | | | | | | | | | | |
| 67 | | | | | | | | | | | | |
| 68 | | | | | | | | | | | | |
| 69 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V690 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 05.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** E: 241 500.58 N: 6 245 996.79 **Elev:** 89.66
**CORE LOGGED:** 05.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V690 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 05.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 500.58 **N:** 6 245 996.79 **Elev:** 89.66
**CORE LOGGED:** 05.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F M Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

55
56
57
58
59
60
61
62
63

E - Some W3 in vertical orientation.

Oxidised Coal - Thin horizon.

Wood Rich - Abundant W2 and W3.

Silty/Sandy Coal - Abundant W2 and W3.
Quartz rich.

PLY: H2, H1b, H1a

INTERVAL: ● ● ● ●

Biomarker: * *

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V691 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 05.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 242 001.24 **N:** 6 245 991.97 **Elev:** 88.59
**CORE LOGGED:** 05.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | STRATIG-RAPHY | | SAMPLING | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG<br>Low Wood / Wood Rich<br>Texture: VF, F, M, Sm, Md, Lg | DESCRIPTION | COLOUR<br>Light – Medium – Dark | GELE-FICATION<br>Low – High | MINERAL MATTER<br>Low – High | PLY | FACIES<br>I – II – III – IV | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 43 | | VF - Weathered at top with sharp boundary from fresh coal. | | | | F2 | | | | | | |
| | | Sand Coal - Grading upward from E to VF. Sand evenly disseminated. | | | | | | | | | | |
| 44 | | | | | | | | | | | | |
| 45 | | VF - High charcoal. Weathered at top. | | | | G5 | | | | | | |
| 46 | | E to WF - Fine tissue, low wood content. | | | | | | | | | | |
| | | VF to F - Decreasing tissue up seam. | | | | | | | | | | |
| 47 | | | | | | G4 | | | | | | |
| | | E - Occasional wood (W1 to W3). | | | | | | | | | | |
| 48 | | F to E - Transitional interval. Decreasing tissue up seam. | | | | | | | | | | |
| | | F - Moderate charcoal, low wood. | | | | | | | | | | |
| 49 | | Wood Rich - Mainly W2 in MF to WF groundmass. | | | | G3 | | | | | | |
| | | E - Some W1 and W2. Small round highly gelified, vertically orientated, possibly root material. | | | | | | | | | | |
| 50 | | | | | | | | | | | | |
| | | Wood Rich - Mainly W2. | | | | G2 | | | | | | |
| 51 | | | | | | | | | | | | |
| | | E - Well gelified, low wood. Some cream inclusions. | | | | G1 | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V691 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 05.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 242 001.24 **N:** 6 245 991.97 **Elev:** 88.59
**CORE LOGGED:** 05.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F M Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 53 | | | | | | | | | | | | |
| 54 | | E - Some bioturbation.<br>Wood Rich - W2 and W3, abundant leaf material. | | | | H2<br>H1b | | | | | | |
| 55 | | Wood Rich Silty Coal - Mainly elongate W2. | | | | H1a | | | | | | |
| 56 | | | | | | | | | | | | |
| 57 | | | | | | | | | | | | |
| 58 | | | | | | | | | | | | |
| 59 | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | |
| 61 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V692 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 06.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 243 375.72 **N:** 6 242 998.77 **Elev:** 84.34
**CORE LOGGED:** 06.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | STRATIG-RAPHY | SAMPLING |
|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F Sm Md Lg) | DESCRIPTION | PLY | INTERVAL |

COLOUR: Light / Medium / Dark
GELE-FICATION: Low / High
MINERAL MATTER: Low / High
FACIES: I II III IV
Petrology / Biomarker / Chemical / Other

17 – Weathered Coal - Dark and friable, silty at top.

18 – Wood Rich - Well gelified W1 and W2.

19 – Weathered Coal - Slight weathering, VF texture discernible. High charcoal, firm.

20

21 – Wood Rich - W1 and W2. Gradational basal contact with decreasing silt up. Slightly weathered at top.

22

23 – Coaly Silt - Increasing carbonaceous content up sequence.

24

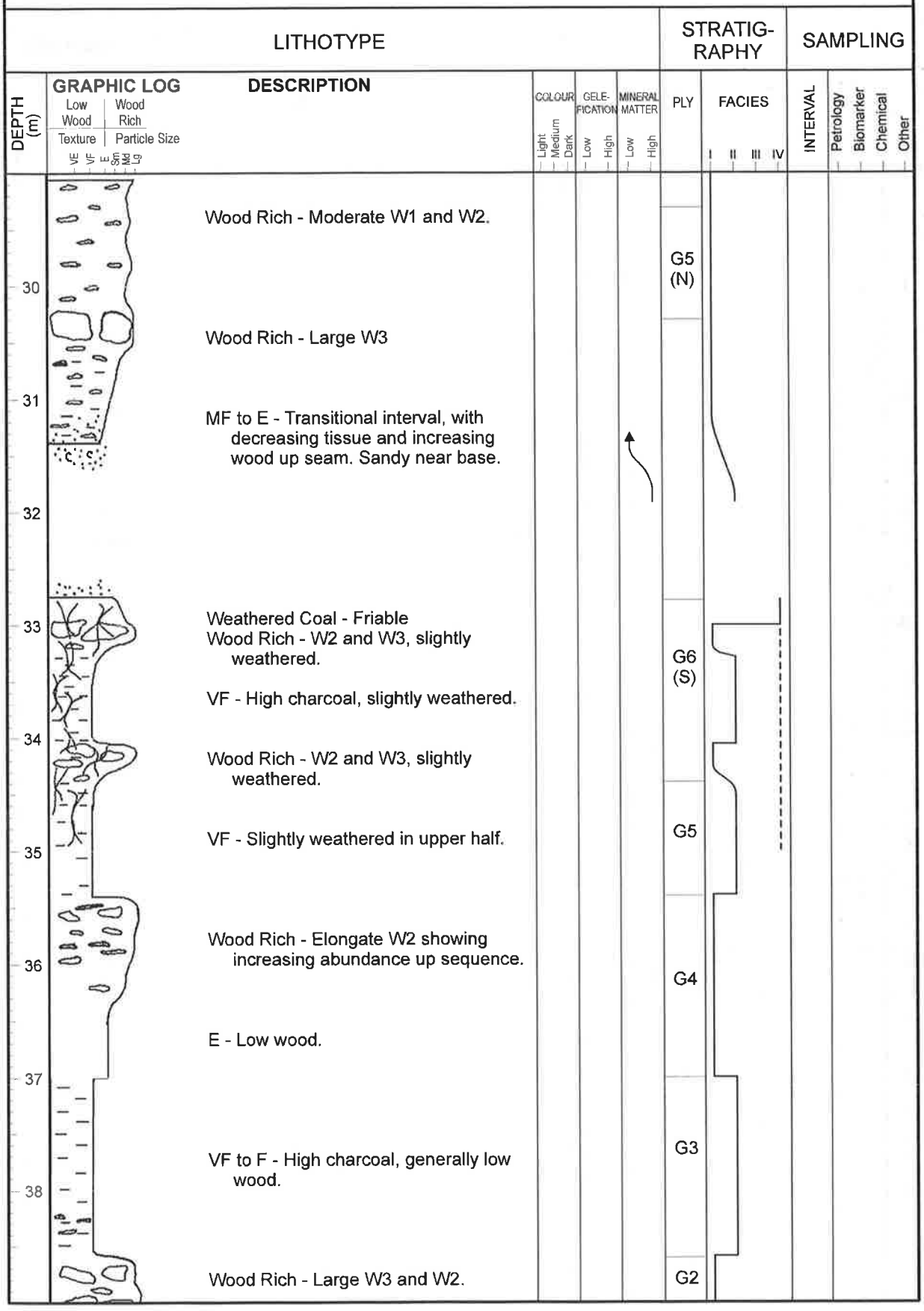
25

PLY: G6 (S); G5; G4 (?)

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V693 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 07.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 748.40 **N:** 6 242 001.06 **Elev:** 83.37
**CORE LOGGED:** 07.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V693 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 07.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 748.40 **N:** 6 242 001.06 **Elev:** 83.37
**CORE LOGGED:** 07.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg; Particle Size) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 40 | | Wood Rich - Large W3 and W2. | | | | G2 | | | | | | |
| 41 | | | | | | | | | | | | |
| 42 | | | | | | | | | | | | |
| 43 | | | | | | | | | | | | |
| 44 | | | | | | | | | | | | |
| 45 | | | | | | | | | | | | |
| 46 | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | |
| 48 | | | | | | | | | | | | |

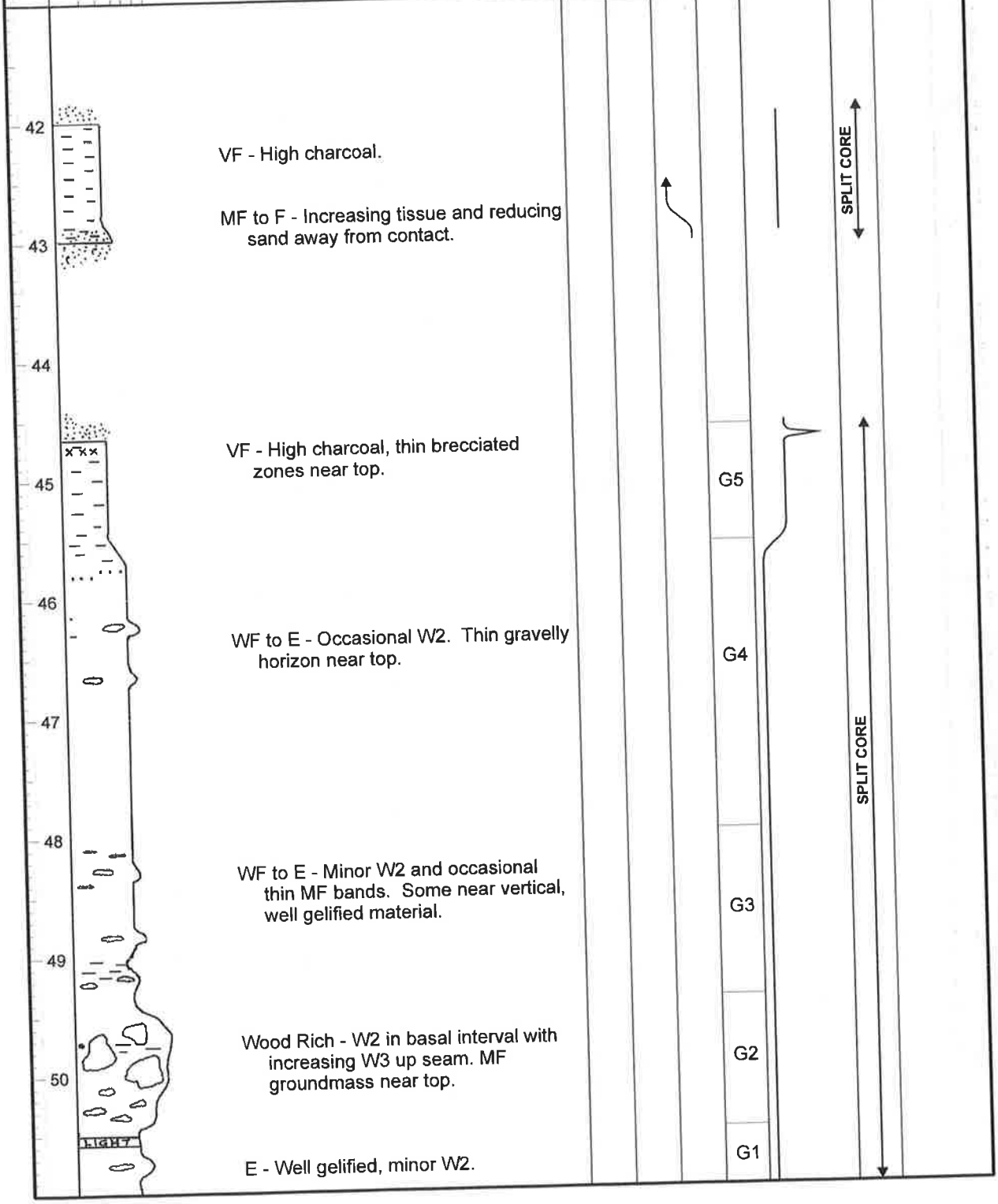
# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V694 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 08.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 242 004.40 **N:** 6 245 502.38 **Elev:** 87.74
**CORE LOGGED:** 08.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light Medium Dark) | GELE-FICATION (Low High) | MINERAL MATTER (Low High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other




VF - High charcoal.

MF to F - Increasing tissue and reducing sand away from contact.

VF - High charcoal, thin brecciated zones near top.

WF to E - Occasional W2. Thin gravelly horizon near top.

WF to E - Minor W2 and occasional thin MF bands. Some near vertical, well gelified material.

Wood Rich - W2 in basal interval with increasing W3 up seam. MF groundmass near top.

E - Well gelified, minor W2.

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V694 | Sheet 2 of 2 |
|---|---|---|

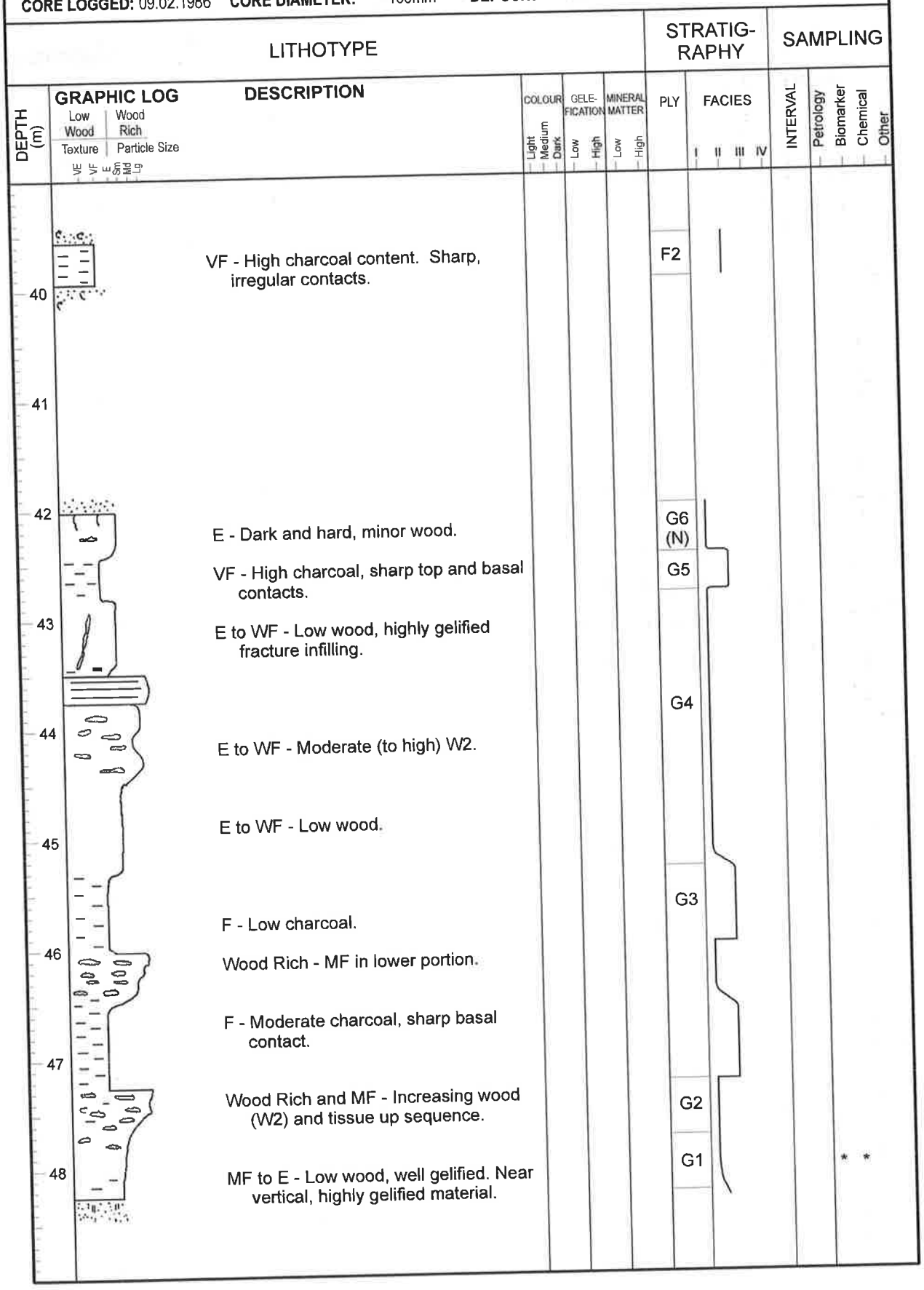
**HOLE DRILLED:** 08.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 242 004.40 **N:** 6 245 502.38 **Elev:** 87.74
**CORE LOGGED:** 08.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 52 | | E - Well gelified, minor W2. | | | | G1 | | | | | | |
| 53 | | | | | | | | | | | | |
| 54 | | E - Low wood. | | | | H2 | | SPLIT CORE | | | | |
| 55 | | Wood Rich - Large fibrous W3, silty. | | | | H1 | | | | | | |
| 56 | | | | | | | | | | | | |
| 57 | | | | | | | | | | | | |
| 58 | | | | | | | | | | | | |
| 59 | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V695 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 09.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 242 502.08 **N:** 6 242 998.34 **Elev:** 86.81
**CORE LOGGED:** 09.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V695 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 09.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 242 502.08 **N:** 6 245 998.34 **Elev:** 86.81
**CORE LOGGED:** 09.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | | STRATIG-RAPHY | | SAMPLING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg; Particle Size) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 50 | | | | | | | | | | | | |
| 51 | | E - Light, some W2 near base. | | | | H2 | | | | | | |
| 52 | | Wood Rich - Large W2 and W3. | | | | H1b | | | | | | |
| 53 | | Wood Rich Silty Coal. | | | | H1a | | | | | | |
| 54 | | | | | | | | | | | | |
| 55 | | | | | | | | | | | | |
| 56 | | | | | | | | | | | | |
| 57 | | | | | | | | | | | | |
| 58 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V701 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 06.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 239 845.89 **N:** 6 248 013.96 **Elev:** 81.66
**CORE LOGGED:** 06.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF E; Particle Size: Sm Md Lg) | DESCRIPTION | COLOUR (Light Medium Dark) | GELE-FICATION (Low High) | MINERAL MATTER (Low High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 52 | | VE - Dark, highly gelified, slightly silty. | | | | | | | * | * | | |
| 53 | | VE - Dark, highly gelified. | | | | F5 | | | * | * | | |
| | | Brecciated Coal - Hard, angular particles in a silty matrix. | | | | F4 | | | * | * | | |
| 54 | | E to WF - Slightly light brown, some W3. Leaf fragments near top. | | | | G6 (N) | | | | | | |
| 55 | | WF to MF - Occasional wood, variable tissue content. | | | | | | | | | | |
| 56 | | MF to F - Variable tissue content. Includes charcoal rich bands. | | | | G5 | | | | | | |
| 57 | | E - Soft, light, some platy W1. | | | | G4 | | | | | | |
| 58 | | E to WF - Large W3 at base. Near vertical well gelified material. | | | | | | | | | | |
| 59 | | MF to WF - Gradational top, moderate charcoal content. | | | | G3 | | | | | | |
| 60 | | E - Moderately woody, (W2 and W3). Fibrous texture in part. | | | | G2 | | | | | | |
| | | E - Well gelified, occasional W2. | | | | G1 (?) | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V701 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 18.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 749.83 **N:** 6 248 503.42 **Elev:** 92.13
**CORE LOGGED:** 18.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 62 | | | | | | | | | | | | |
| 63 | | | | | | | | | | | | |
| 64 | | E - Low wood, silty. | | | | H2 | | | | | | |
| 65 | | Wood Rich - W3 and W2, silty near base. | | | | H1b<br>H1a | | | | | | |
| 66 | | | | | | | | | | | | |
| 67 | | | | | | | | | | | | |
| 68 | | | | | | | | | | | | |
| 69 | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V702 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 19.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 239 999.1 **N:** 6 242 499.62 **Elev:** 83.76
**CORE LOGGED:** 19.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF, F, M, C) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELIFICATION (Low, High) | MINERAL MATTER (Low, High) | STRATIGRAPHY: PLY | STRATIGRAPHY: FACIES (I, II, III, IV) | SAMPLING: INTERVAL | SAMPLING: Petrology, Biomarker, Chemical, Other |
|---|---|---|---|---|---|---|---|---|---|
| 36 | | Weathered Coal - Dark, friable, low wood. | | | | | | SPLIT CORE | |
| 37 | | | | | | | | | |
| 38 | | Wood - W3, vertical orientation, soft. Sand laminae at base. | | | | G6 (S) | | | |
| 39 | | Wood Rich - W2 and W3, slight increase in abundance up sequence. Slightly weathered, sandy. | | | | | | | |
| 40 | | E - Some wood, slightly weathered. | | | | | | | |
| | | VF - High charcoal content. | | | | G5 | | | |
| 41 | | | | | | | | | |
| | | E to WF - Some W2 in lower portion. | | | | G4 | | SPLIT CORE | |
| 42 | | | | | | | | | |
| 43 | | VF - High charcoal content near top. | | | | G3 | | | |
| 44 | | Wood Rich - W2 and W3 abundant. | | | | G2 | | | |
| 45 | | E - Fine sand laminae near base, minor wood. | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V703 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 20.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 004.74 **N:** 6 244 527.62 **Elev:** 101.78
**CORE LOGGED:** 20.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Mid Lg; Particle Size) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 59 | | VF - Moderate charcoal content, sharp basal contact. | | | | G5 (N) | | | | | | |
| | | E to WF - Low wood. | | | | | | | | | | |
| 60 | | WF - Some W2, increasing up sequence as large tissue content reduces. | | | | G4 | | | | | | |
| 61 | | MF - Moderate W2 content. | | | | | | | | | | |
| 62 | | F to VF - Some W1. | | | | G3 | | | | | | |
| | LIGHT | E - Light, low wood. | | | | | | | | | | |
| 63 | | | | | | G2 | | | * | * | | |
| | | Woody - W2 and W3, within WF to MF groundmass. | | | | | | | * | | | |
| 64 | | WF to MF - Low wood. | | | | | | | * | | | |
| | | VF - High charcoal content in part. | | | | G1 | | | * | | | |
| 65 | | | | | | | | | | | | |
| 66 | | | | | | | | | | | | |
| 67 | | Wood Rich - W3 (and W2). | | | | H1a | | | | | | |
| | | | | | | H1b | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V704 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 06.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 001.40 **N:** 6 245 498.96 **Elev:** 101.68
**CORE LOGGED:** 06.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sn Mn Cp; Particle Size) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

58

VE - Silty, dark, highly gelified.

F5

Brecciated Coal - Hard, dark particles, mostly < 2 mm.

F4

59

Wood Rich - Mainly W3, E groundmass.

F3

F2

60

VF - Commonly high charcoal content, although variable. Very low wood component.

61

E - Minor wood, sandy near base.

F1

62

63

VF - Moderate charcoal content. Contains a thin brecciated coal horizon.

G5

WF to MF - Gradual increase in tissue abundance up sequence.

64

65

E to MF - Contains multiple cycles of progressively reducing tissue content up sequence, (i.e. MF > WF > E > Light).

G4

SPLIT CORE

66

VF - Moderate charcoal content, low wood.

G3

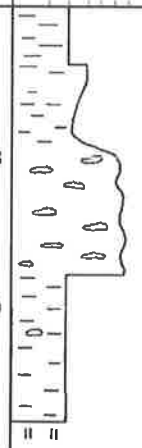
# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V704 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 06.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 001.40 **N:** 6 245 498.96 **Elev:** 101.68
**CORE LOGGED:** 06.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F E Sm Md Lg) | DESCRIPTION | COLOUR (Light – Medium – Dark) | GELE-FICATION (Low – High) | MINERAL MATTER (Low – High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other



68

VF to E - Progressive decrease in platy tissue up sequence.

Wood Rich - Mainly W2, MF to E groundmass.

69

F to VF - Platy tissue, low charcoal content. Minor W1 and W2 and some near vertical, well gelified material.

70

71

72

E - Leaf fragments common, some W2. Bioturbated at top.

73

Wood Rich - W3, fine sand and silt common.

74

75

76

G3 | G2 | G1 | H2 | H1a

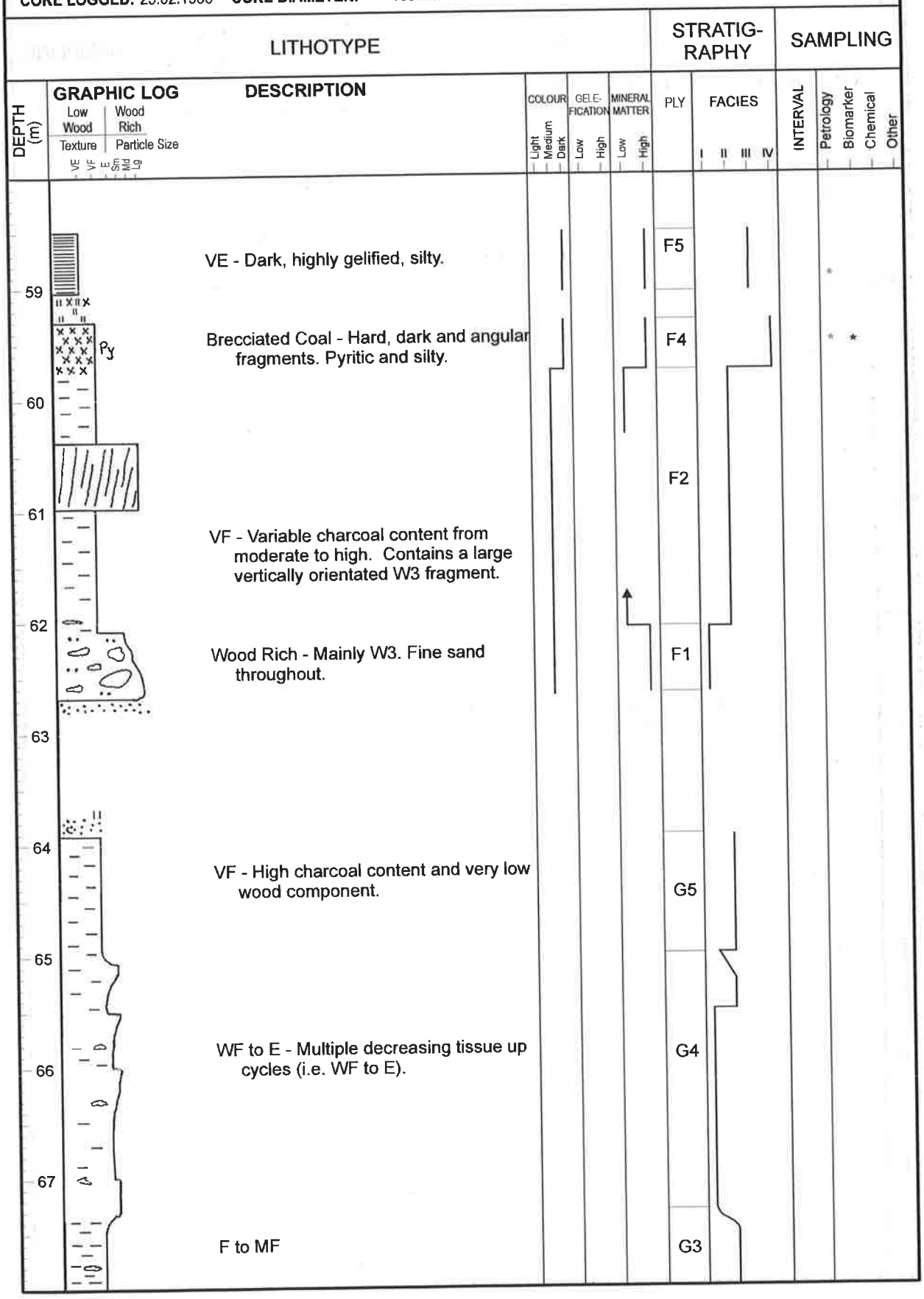
SPLIT CORE

SPLIT CORE

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V705 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 25.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 999.32 **N:** 6 246 039.55 **Elev:** 99.79
**CORE LOGGED:** 25.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V705 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 25.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 999.32 **N:** 6 246 039.55 **Elev:** 99.79
**CORE LOGGED:** 25.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F M C VC) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 69 | | F - Low (to moderate) charcoal content. Variable small tissue content. Some W2. | | | | G3 | | | | | | |
| | | Wood Rich - W2 and W3. MF groundmass. | | | | G2 | | | | | | |
| 70 | | WF to MF - Well gelified, some wood. | | | | G1 | | | | | | |
| 71 | | | | | | | | | | | | |
| 72 | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | |
| 74 | | WF - Leaf fragments locally common. Some W2. | | | | H2 | | | | | | |
| 75 | | Wood Rich - W3 common, silty and sandy. | | | | H1a | | | | | | |
| 76 | | | | | | | | | | | | |
| 77 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V706 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 23.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 748.95 **N:** 6 247 501.31 **Elev:** 94.99
**CORE LOGGED:** 23.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture; Particle Size VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

55
56
57
58
59
60
61
62
63

VE - Very dark, soft and well gelified.

Brecciated Coal - Hard, brittle and vesicular. Silty matrix.

F (to VF) - High charcoal content. Very low wood component.

E to WF - Gradual increase in tissue abundance up seam. Sandy.

E - Hard, minor wood, sandy at top.

F - Moderate charcoal, low wood. Includes a thin brecciated horizon. Leaf rich in upper portion.

Wood Rich - Mainly W2. Some vertically orientated well gelified material.

E to WF - Low wood, light in part.

Wood Rich - WF, slightly sandy.

F to MF - Low charcoal content.

E to WF - Generally low wood.

Wood Rich - Abundant W2, well gelified groundmass.

PLY: F5, F4, F2, F1, G6 (N), G5, G4, G3, G2

LIGHT

SPLIT CORE

SPLIT CORE

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V706 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 23.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 748.95 **N:** 6 247 501.31 **Elev:** 94.99
**CORE LOGGED:** 23.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 65 | | | | | | G2 | | | | | | |
| 66 | | | | | | | | | | | | |
| 67 | | E to WF - Low wood content, bioturbated. | | | | H2 | | SPLIT CORE | | | | |
| 68 | | Moderately Woody - W2 with some W1. WF groundmass. | | | | H1b | | | | | | |
| 69 | | Wood Rich - W2 and W3. Silty. | | | | H1a | | | | | | |
| 70 | | Wood Rich - Mainly W2, sandy. | | | | | | | | | | |
| 71 | | | | | | | | | | | | |
| 72 | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V707 | Sheet 1 of 2 |
|---|---|---|

**HOLE DRILLED:** 24.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 248.65 **N:** 6 248 001.39 **Elev:** 91.81
**CORE LOGGED:** 24.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F M Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 46 | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | |
| 48 | | | | | | | | | | | | |
| 49 | | | | | | | | | | | | |
| 50 | | WF | | | | | | | | | | |
| 51 | | F to VF - Increasing charcoal content up seam. | | | | F2 | | | | | | |
| 52 | | E - Minor wood content, sharp contacts. | | | | | | | | | | |
| 53 | | F to VF - Moderate charcoal content, low wood component. | | | | | | | | | | |
| 54 | | F to MF - Moderate W2 abundance, well gelified groundmass. | | | | F1 | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V707 | Sheet 2 of 2 |
|---|---|---|

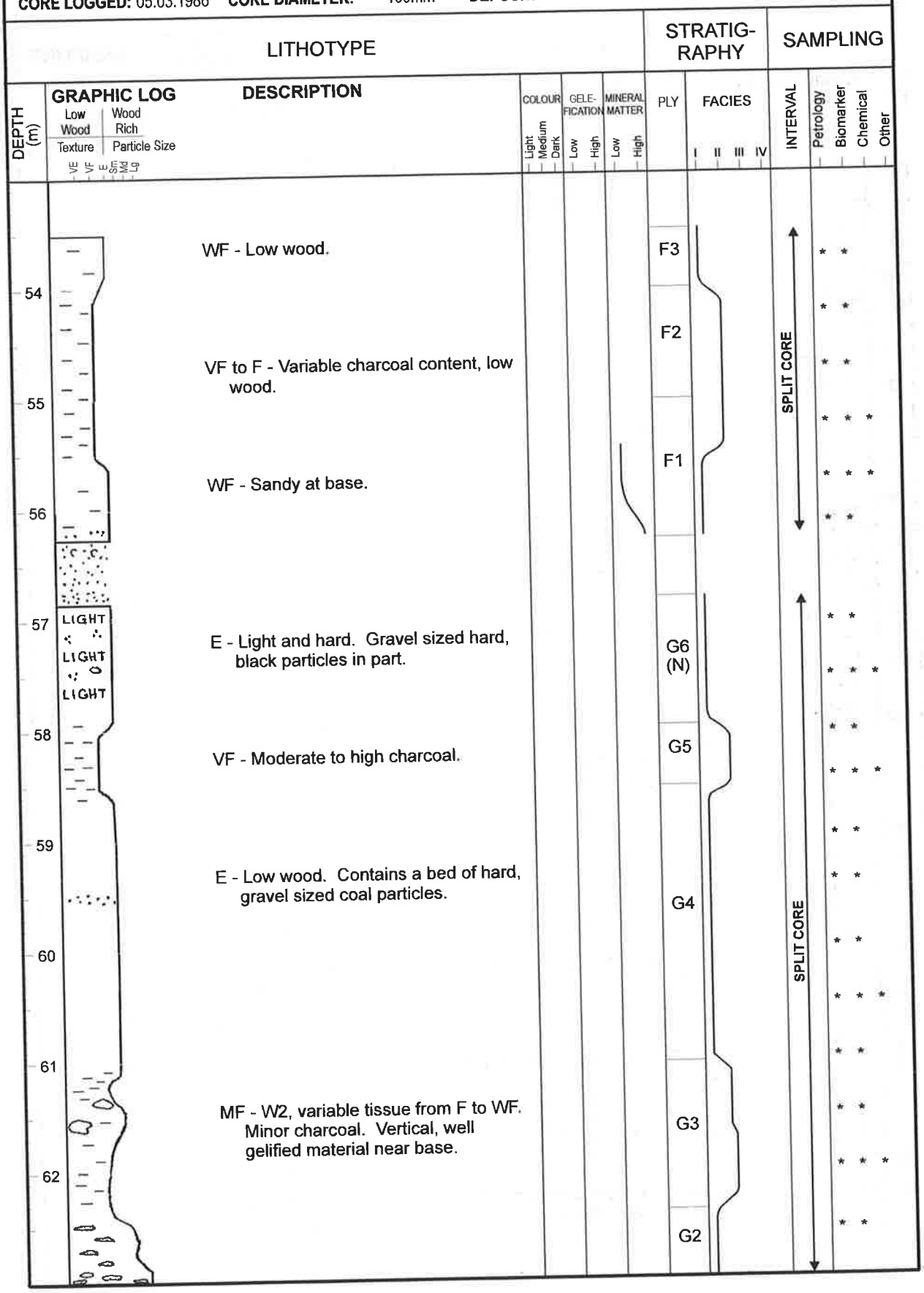
**HOLE DRILLED:** 24.02.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 248.65 **N:** 6 248 001.39 **Elev:** 91.81
**CORE LOGGED:** 24.02.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VF F M C VC) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 56 | LIGHT | WF to MF - Light, rich in leaf fragments. | | | | | | | | | | |
| | | WF to E - Moderate W2 and W3 content. | | | | G6 (N) | | | | | | |
| 57 | PALE | E - Pale | | | | | | | | * | * | |
| | | E - Moderate W2 and W3 content. | | | | | | | | | | |
| 58 | | VF | | | | G5 | | | | | | |
| | | Wood Rich - W2 and W3. WF groundmass. | | | | | | | | | | |
| 59 | | WF - Locally wood rich near base. | | | | | | | | | | |
| | | | | | | G4 | | | | | | |
| 60 | | E - Light brown, minor W2 particles. Some vertically orientated, well gelified inclusions. | | | | | | | | | | |
| 61 | | | | | | | | | | | | |
| 62 | | F to VF - Low to moderate charcoal abundance. | | | | G3 | | | | | | |
| 63 | | MF to WF - Decreasing tissue content up sequence. Low wood. | | | | | | | | | | |
| | | Wood Rich - W2 and W3. | | | | G2 | | | | | | |
| 64 | | E - Moderate W2 abundance. Some vertical, well gelified material. | | | | | | | | * | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V714 | Sheet 1 of 2 |
|---|---|---|

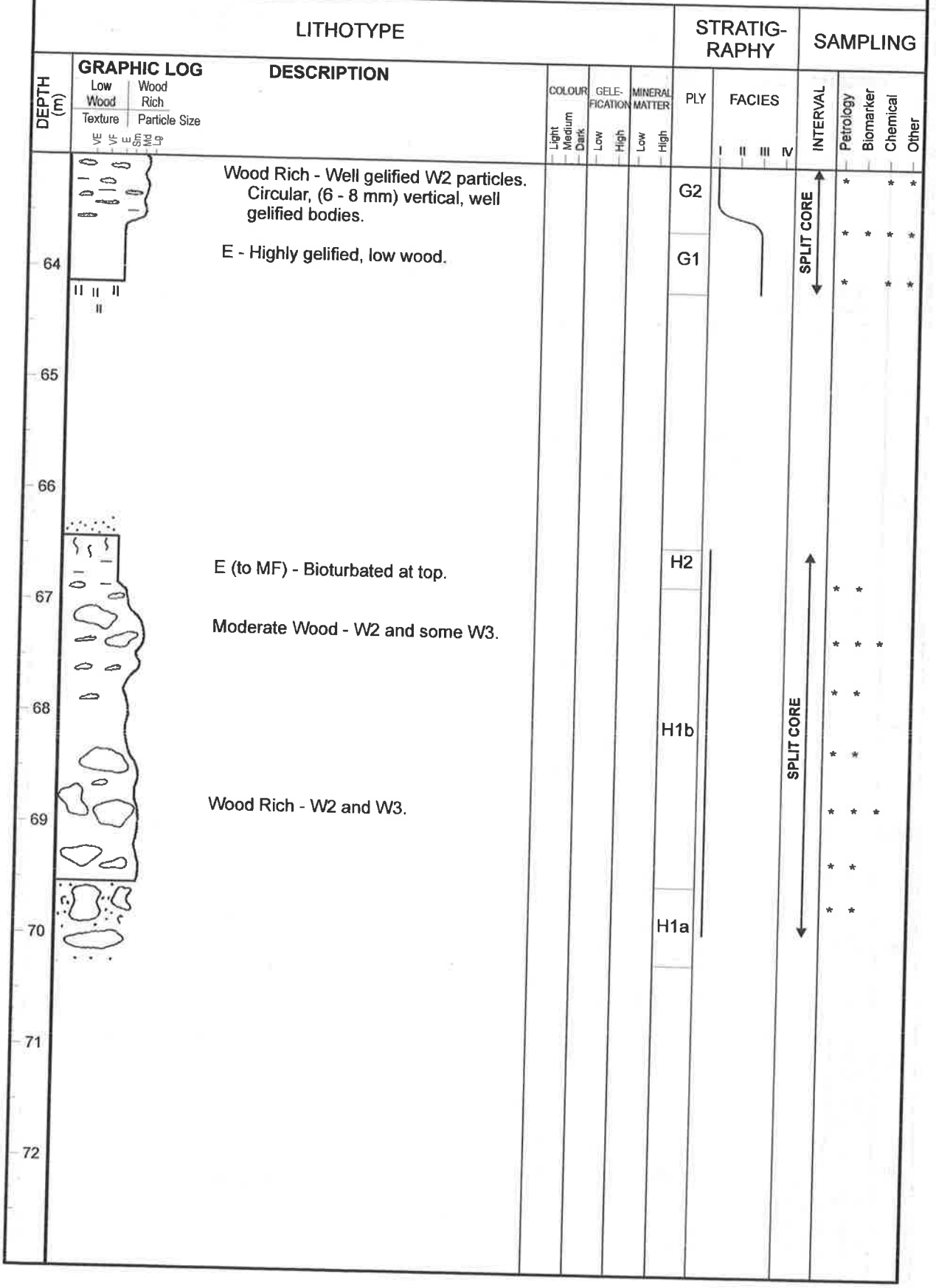
**HOLE DRILLED:** 05.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 211.76 **N:** 6 247 497.37 **Elev:** 91.66
**CORE LOGGED:** 05.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V714 | Sheet 2 of 2 |
|---|---|---|

**HOLE DRILLED:** 05.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 211.76 **N:** 6 247 497.37 **Elev:** 91.66
**CORE LOGGED:** 05.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



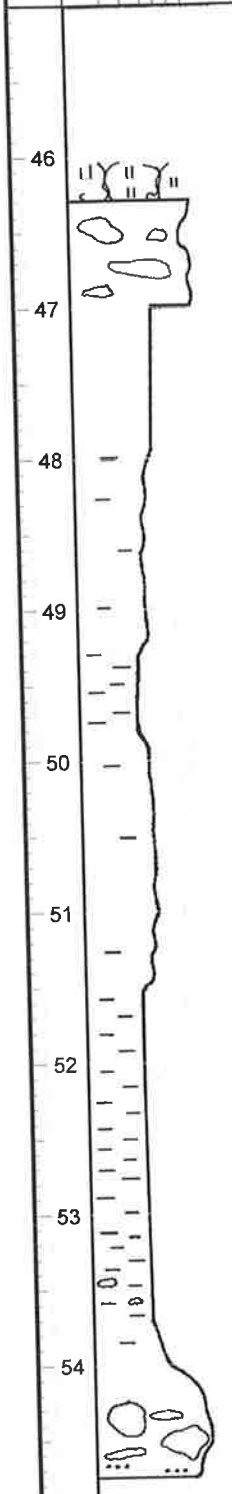
# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V715 | Sheet 1 of 3 |
|---|---|---|

**HOLE DRILLED:** 06.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 239 845.89 **N:** 6 248 013.96 **Elev:** 81.66
**CORE LOGGED:** 06.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VE VF E Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other




Wood Rich - W2 and W3. Leafy.

E - Low wood, possibly slightly weathered.

MF - Variable charcoal, low wood. Possible slightly weathered. Soft.

F to VF - High charcoal.

MF - Low wood, possibly slightly weathered.

VF - Moderate to high charcoal near base and decreasing up sequence. Minor W2 near base.

E - Grades rapidly to tissue rich groundmass.

Wood rich - W2 and W3. Fine sand near base.

PLY: F3 | F2 (?) | F2 | F1

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V715 | Sheet 2 of 3 |
|---|---|---|

**HOLE DRILLED:** 06.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 239 845.89 **N:** 6 248 013.96 **Elev:** 81.66
**CORE LOGGED:** 06.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VF F M Mg; Particle Size: VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 56 | LIGHT / LIGHT | Light - E groundmass, hard, minor wood near top. | | | | G5 (N) | | | | | | |
| 57 | | Wood Rich - W3 and W2. | | | | | | | | | | |
| 58 | | E to WF - Low wood. | | | | | | | | | | |
| 59 | | MF - Low charcoal. | | | | G4 | | | | | | |
| 60 | | E to WF - Low wood. | | | | | | | | | | |
| 61 | | MF - Low wood, low charcoal, variable tissue content with gradational decease from centre. | | | | G3 | | | | | | |
| 62 | | Wood Rich - Elongate W2, some in vertical orientation near top. Well gelified. | | | | G2 | | | | | | |
| 63 | | | | | | | | | | | | |
| 64 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V715 | Sheet 3 of 3 |
|---|---|---|

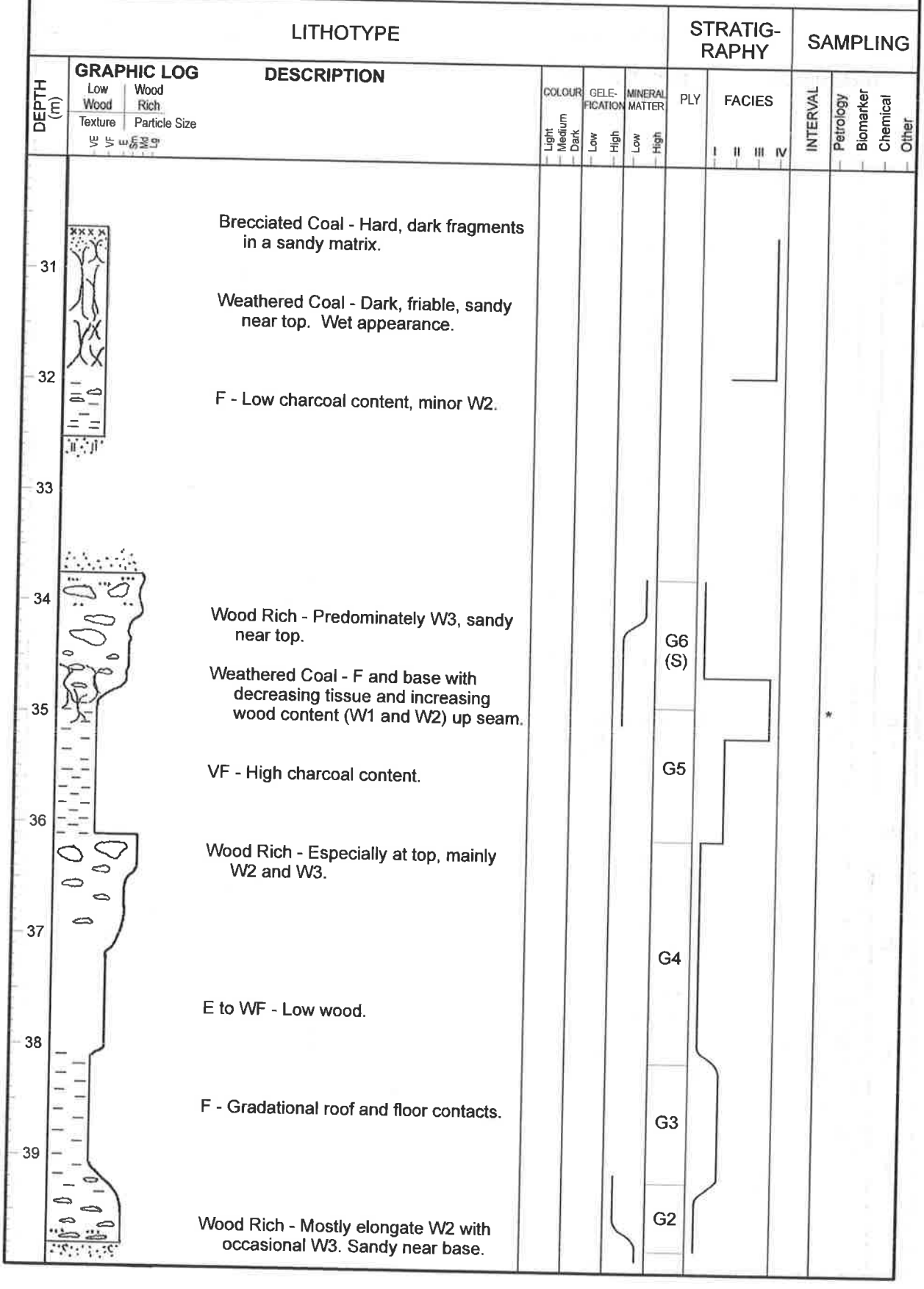
**HOLE DRILLED:** 06.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 239 845.89 **N:** 6 248 013.96 **Elev:** 81.66
**CORE LOGGED:** 06.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 66 | | Wood Rich - Silty | | | | | | | | | | |
| | | E to WF - Slightly silty, possibly weathered. | | | | | | | | | | |
| 67 | | Moderate Wood - W2, leaf rich. | | | | H1b | | | | | | |
| 68 | | Wood Rich - W3. | | | | | | | | | | |
| 69 | | Wood Rich - Elongate W2, sandy near base. | | | | | | | | | | |
| | | | | | | H1a | | | | | | |
| 70 | | Woody, Sandy Coal | | | | | | | | | | |
| 71 | | | | | | | | | | | | |
| 72 | | | | | | | | | | | | |
| 73 | | | | | | | | | | | | |
| 74 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V716 | Sheet 1 of 1 |
|---|---|---|

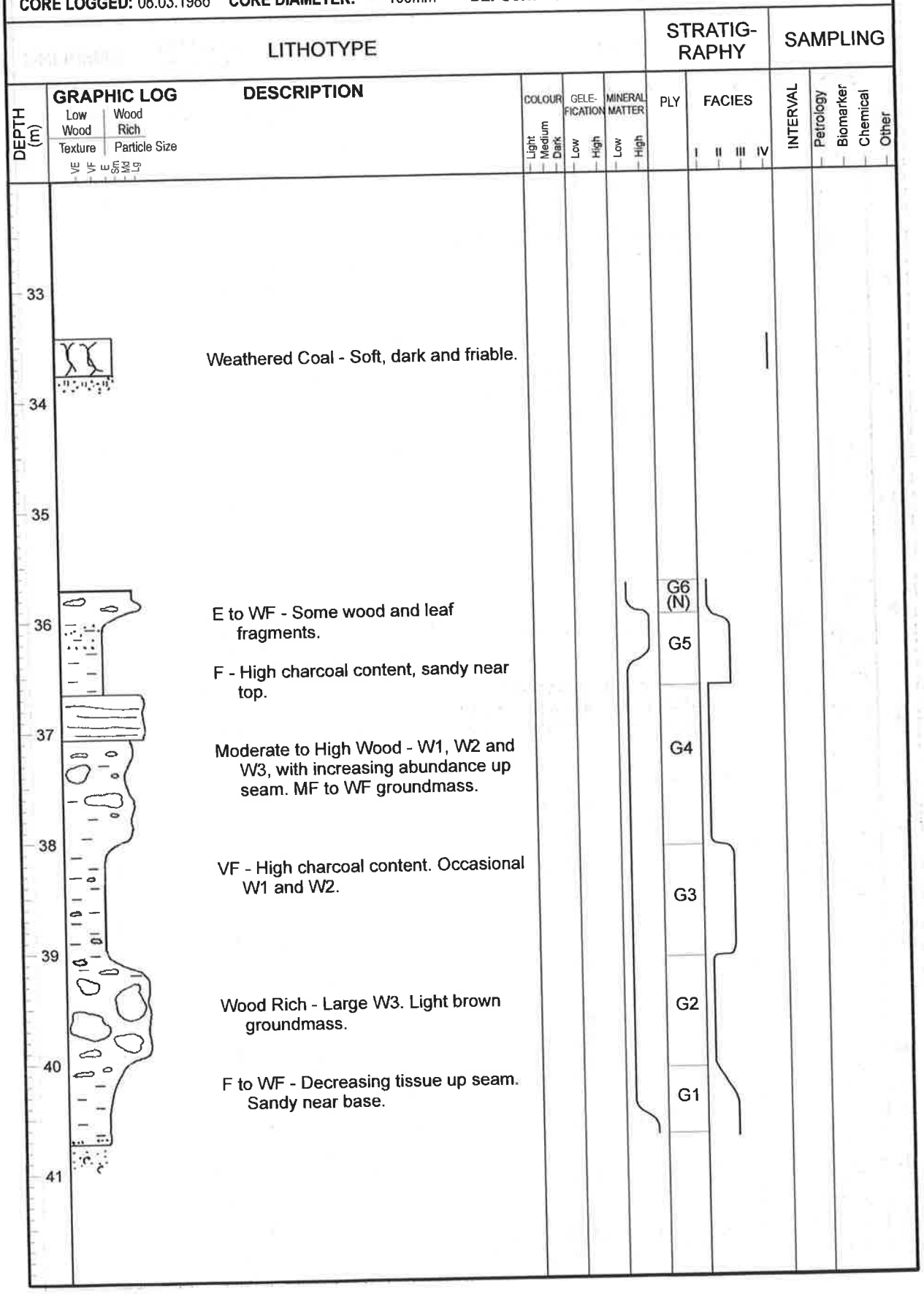
**HOLE DRILLED:** 07.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 241 500.00 **N:** 6 242 450.00 **Elev:** 81.65
**CORE LOGGED:** 07.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V717 | Sheet 1 of 1 |
|---|---|---|

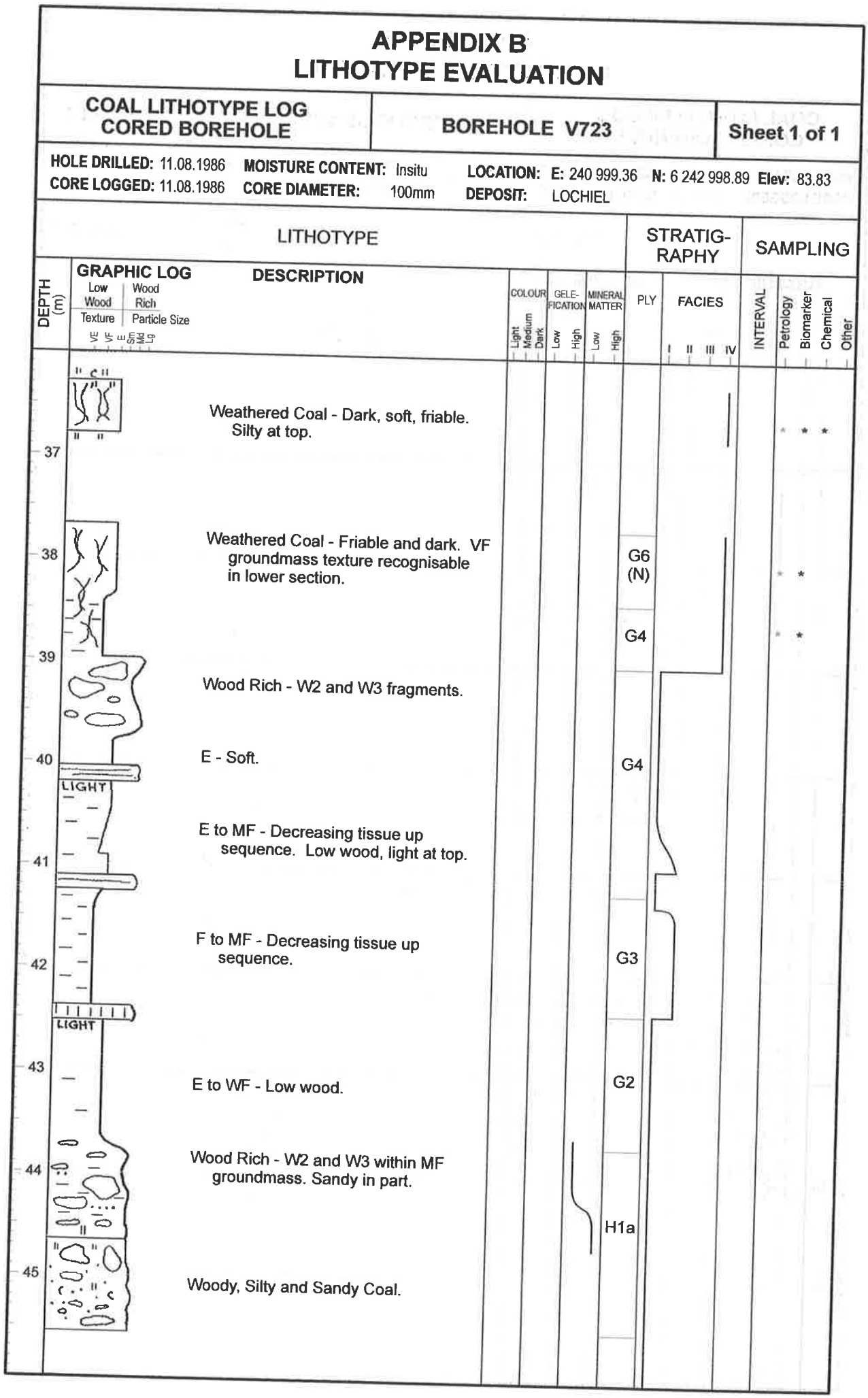
**HOLE DRILLED:** 08.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 239 579.93 **N:** 6 243 000.02 **Elev:** 79.29
**CORE LOGGED:** 08.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V723 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 11.08.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 999.36 **N:** 6 242 998.89 **Elev:** 83.83
**CORE LOGGED:** 11.08.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V724 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 11.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 239 948.00 **N:** 6 243 448.00 **Elev:** 79.70
**CORE LOGGED:** 11.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture / Particle Size: VE VF E Sm Md Lg) | DESCRIPTION | COLOUR (Light, Medium, Dark) | GELE-FICATION (Low, High) | MINERAL MATTER (Low, High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

33

F to VF - High charcoal content, low wood except near seam roof.

34

WF - Moderate wood content with W3 and leaf fragments common near base. W1 and W2 dominant in upper portion.

35

E to WF - Low wood.

36

MF to F - Variable fine tissue content. Charcoal content increases with tissue abundance.

37

Wood Rich - Large W3, with some W2.

38

Moderate Wood - Predominately elongate W2 in a MF groundmass. Sandy in part.

39

Wood Rich - Mainly large W3. Sandy in basal and central sections.

40

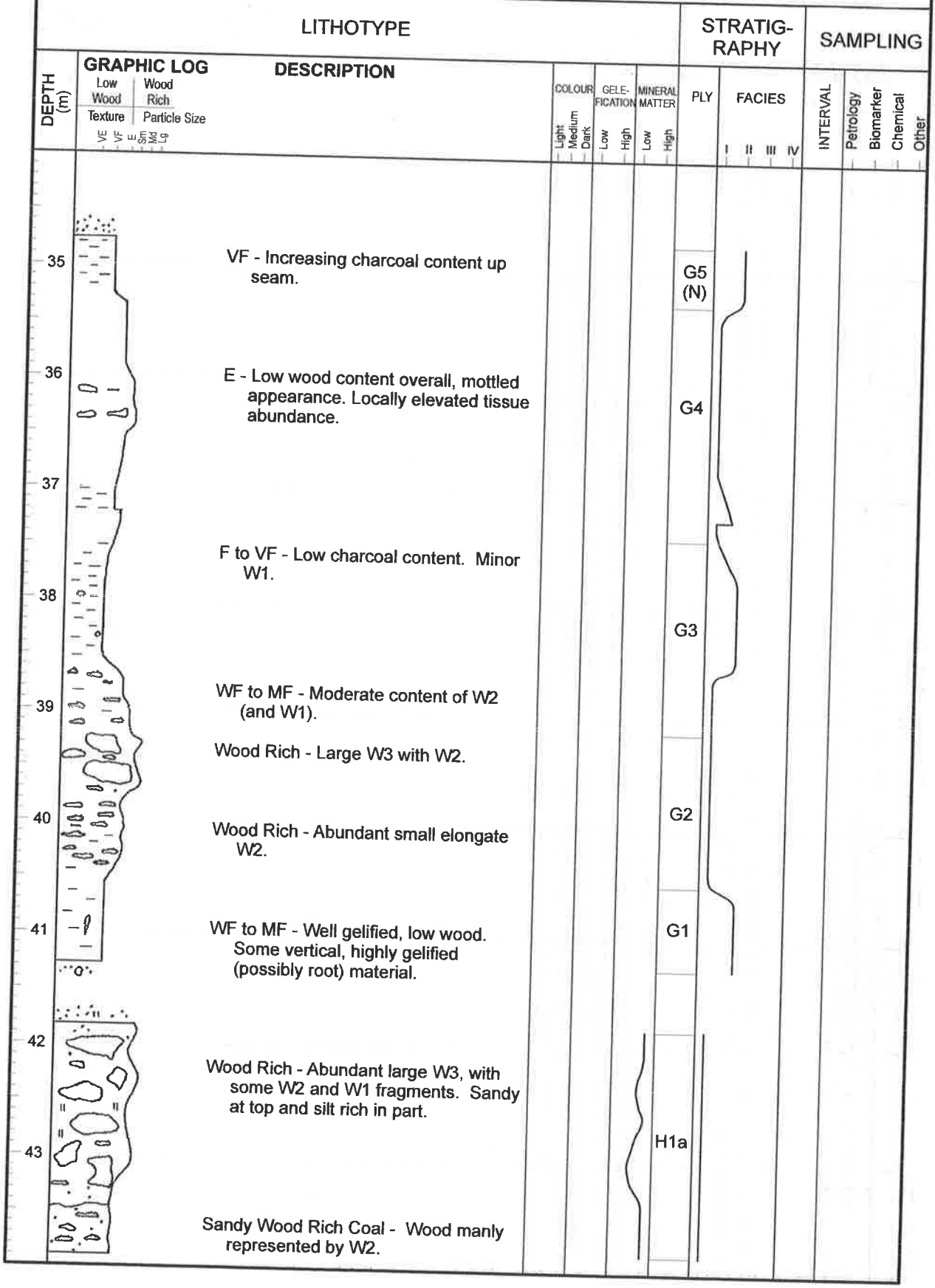
41

PLY: G6, G5, G4, G3, G2, H1a

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE V725 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 13.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 095.62 **N:** 6 243 978.67 **Elev:** 78.80
**CORE LOGGED:** 13.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V726 | Sheet 1 of 3 |
|---|---|---|

**HOLE DRILLED:** 14.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 492.43 **N:** 6 244 981.27 **Elev:** 79.50
**CORE LOGGED:** 14.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF E Sm Md Lg; Particle Size) | DESCRIPTION | COLOUR (Light Medium Dark) | GELE-FICATION (Low High) | MINERAL MATTER (Low High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

27
28
29
30
31
32
33
34
35

VE - Dark, highly gelified, silty.

Brecciated Coal - Hard fragments within a silty matrix.

F to MF - Tissue most abundant in centre of ply. Sandy near base.

Sandy Coal - E groundmass. Sand disseminated and in fine beds.

PLY: F5, F4, F2, F1

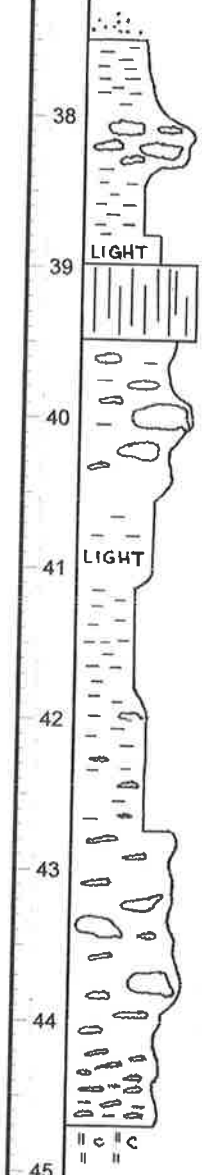
# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V726 | Sheet 2 of 3 |
|---|---|---|

**HOLE DRILLED:** 14.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 492.43 **N:** 6 244 981.27 **Elev:** 79.50
**CORE LOGGED:** 14.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other




WF to F - Increasing tissue abundance up seam.
Wood Rich - W1 and W2 with some W3.

F - High charcoal content.

E - Light coloured, low wood content.

Wood Rich - W2 with some W3 within a WF groundmass. Large vertical W3 at top of ply.

E to WF - Low wood, light band at base.

F - Low charcoal content.

MF - Some well gelified W2.

Wood Rich - Mainly well gelified elongate W2, with minor W3.

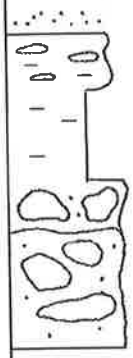
Wood Rich - Well gelified small elongate W2 and W1, in a WF groundmass.

PLY: G5 | G4 | G3 | G2 | G1

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V726 | Sheet 3 of 3 |
|---|---|---|

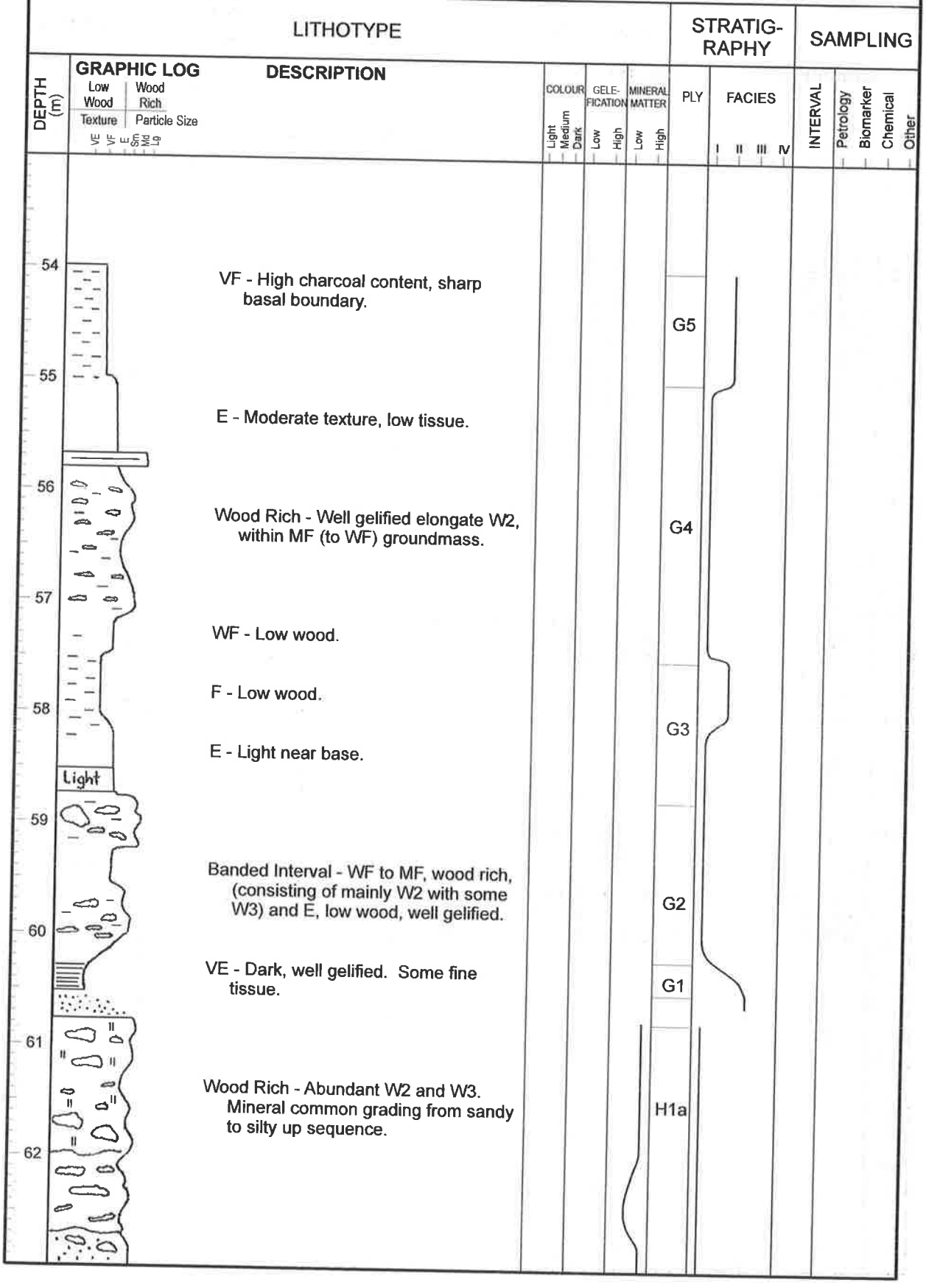
**HOLE DRILLED:** 14.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 492.43 **N:** 6 244 981.27 **Elev:** 79.50
**CORE LOGGED:** 14.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL

| LITHOTYPE | | | | | | STRATIG-RAPHY | | SAMPLING | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF F Sm Md Lg; Particle Size) | DESCRIPTION | COLOUR (Light / Medium / Dark) | GELE-FICATION (Low / High) | MINERAL MATTER (Low / High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other |
| 47 |  | MF - Moderate W2.<br><br>E to WF - Low wood content.<br><br>Wood Rich - W2 and W3 fragments. Mineral content decreases up seam. | | | | H2<br>H1b<br>H1a | | | | | | |
| 48 | | | | | | | | | | | | |
| 49 | | | | | | | | | | | | |
| 50 | | | | | | | | | | | | |
| 51 | | | | | | | | | | | | |
| 52 | | | | | | | | | | | | |
| 53 | | | | | | | | | | | | |
| 54 | | | | | | | | | | | | |
| 55 | | | | | | | | | | | | |

# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG CORED BOREHOLE | BOREHOLE V749 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 31.03.1986 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 240 691.05 **N:** 6 244 023.11 **Elev:** 96.38
**CORE LOGGED:** 31.03.1986 **CORE DIAMETER:** 100mm **DEPOSIT:** LOCHIEL



# APPENDIX B
# LITHOTYPE EVALUATION

| COAL LITHOTYPE LOG<br>CORED BOREHOLE | BOREHOLE S12 | Sheet 1 of 1 |
|---|---|---|

**HOLE DRILLED:** 15.05.1987 **MOISTURE CONTENT:** Insitu **LOCATION:** **E:** 242 963.40 **N:** 6 244 830.90 **Elev:** 83.50
**CORE LOGGED:** 15.05.1987 **CORE DIAMETER:** Pit Traverse **DEPOSIT:** LOCHIEL

LITHOTYPE | STRATIG-RAPHY | SAMPLING

DEPTH (m) | GRAPHIC LOG (Low Wood / Wood Rich; Texture: VE VF E Sm Md Lg; Particle Size) | DESCRIPTION | COLOUR (Light Medium Dark) | GELE-FICATION (Low High) | MINERAL MATTER (Low High) | PLY | FACIES (I II III IV) | INTERVAL | Petrology | Biomarker | Chemical | Other

0
Wood Rich - Large W3 up to 0.2 m in diameter. Irregularly distributed sand.
G6
E - Medium to light, low wood.
1
G5
F to VF - Dark, platy and charcoal rich. Low wood content.
2
G4
3
Wood Rich - Abundant W3 (up to 0.25 m in diameter), with some W2 and W1. E groundmass.
4
G3
Moderate Wood - W2 and W3 in approximately equal proportion. Upward gradation from MF to E groundmass.
5
G2
Wood Rich - Well gelified, elongate W2 (averaging approximately 0.02 m). Sandy and tissue rich near base.
G1
6
7
8

# APPENDIX C
# MACERAL ANALYSIS

Maceral data gathered during the course of this project from coals of the Lochiel and Bowmans Deposits is presented in this Appendix.

**APPENDIX C1: Sub-maceral definition**
Outlines criteria for sub-maceral definition

**APPENDIX C2: Maceral data for point counts**
Presents point count data and maceral indices for all samples evaluated

# APPENDIX C1
# SUB-MACERAL DEFINITION

During micropetrographic evaluation subtle differences were noted in the characteristics of some macerals. Where these could be consistently recognised sub-macerals and maceral qualifiers were informally defined.

The standard criteria applied to define the sub-macerals and maceral qualifiers are outlined below and photographic examples presented in Plates 5.4, 5.8 and 5.10 - 5.13.

## C1.1 LIPTINITE SUB-MACERALS

### C1.1.1 Cutinite

In most brown coals cuticle occurs in low concentration (Stach *et al.*, 1982) is relatively thin and can readily be destroyed by organisms in the upper peat surface. The diversity of cutinite forms was highlighted by Scott (2002). Three distinct forms of cutinite occur in Lochiel and Bowmans coals (Plate 5.8). Furthermore, the maceral associations within which they occur differ considerably.

*Sub-maceral identifier:* **Cutinite "L"**
*Occurrence:* Represents the most common of the cutinite sub-macerals and occurs in both deposits in facies I coals.
*Size and shape:* Thick (15-20 μm) and elongate (up to 250 μm long). Phytoclasts are resistant and generally large.
*Fluorescence colours:* Relatively bright, often greenish yellow.
*Common associations:* Generally occurs in wood rich coals in association with massive telovitrinite.
*Origin:* Thought to represent leaf cuticle (A. Rowett pers. comm., 1992)
*Distinction from other cutinite:* Thickness and fluorescence.

*Sub-maceral identifier:* **Cutinite "M"**
*Occurrence:* Relatively uncommon and generally restricted to wood-poor, sub-facies IIb coals from the Lochiel Deposit.
*Size and shape:* Very thin and elongate (1 to 2 by $\geq$ 250 μm) and often well preserved.
*Fluorescence colours:* Relatively dull brownish yellow.
*Common associations:* Occurs in well gelified, wood-poor coals and is commonly attached to elongate groundmass telovitrinite phytoclasts.

*Origin:* Possibly represents root, or fine stem cuticle (A. Rowett, pers. comm., 1992)
*Distinction from other cutinite:* Thin, strongly elongate form and association with groundmass telovitrinite.

*Sub-maceral identifier:* **Cutinite "N"**
*Occurrence:* Relatively uncommon and restricted to Lochiel facies III coals.
*Size and shape:* Generally occurs as several fine bands within a broadly elongate association of 100 to 150 μm).
*Fluorescence colours:* Slightly greenish yellow.
*Common associations:* Occurs in very well gelified, wood-poor facies III coals, within a detrovitrinite groundmass.
*Origin:* Possibly autochthonous preservation of fine stem cuticle.
*Distinction from other cutinite:* Thin, wispy form and association with fine detrovitrinite groundmass.

### C1.1.2 Resinite

Resinite is derived from resins as well as balsams, latexes, fats and waxes and shows a wide range in chemical composition (Teichmuller, 1989; Scott, 2002). Botanically they may occur as secretions of cell wall, filling cell lumens and wound drops. In Lochiel and Bowmans coals resinite occurs in a variety of forms and three distinct types were defined in line with morphology, size and association (Plate 5.10).

*Sub-maceral identifier:* **Resinite "B"**
*Occurrence:* Widespread and common throughout facies I coals.
*Size and shape:* Rounded, or elongate bodies (10 - 40 μm), broadly consistent with cell lumen dimensions. Particles occur in isolation within a detrovitrinite groundmass.
*Fluorescence colours:* Dull brownish yellow, to yellow.
*Common associations:* Suberinite, liptodetrinite and massive telovitrinite.
*Origin:* Possibly cell lumen infilling.
*Distinction from other resinite:* Rounded to elongate morphology and size consistent with cell lumens.

*Sub-maceral identifier:* **Resinite "C"**
*Occurrence:* Generally restricted to woody, telovitrinite rich sub-facies Ia coals.
*Size and Shape:* Single large, homogeneous particles (up to 250 μm), commonly showing a vesicular form (i.e. small 2 to 5 μm voids).
*Fluorescence colours:* Dull brownish yellow to yellow.
*Common associations:* Predominantly with suberinite, liptodetrinite and massive telovitrinite.
*Origin:* Possibly wound resins.

*Distinction from other resinite:* Phytoclasts are significantly larger than other resinite varieties.

*Sub-maceral identifier:* **Resinite "D"**
*Occurrence:* Generally restricted to the woody, telovitrinite rich sub-facies Ia coals.
*Size and shape:* Large cellular associations (i.e. groupings of several smaller bodies) often within telovitrinite phytoclasts. The size and morphology of individual particles is consistent with resinite from intact cell infillings.
*Fluorescence colours:* Dull brownish yellow to yellow.
*Common associations:* Predominantly with suberinite, liptodetrinite and massive telovitrinite
*Origin:* Intact cell infillings.
*Distinction from other resinite:* Association of several cellular shaped bodies.

### C1.1.3 Suberinite

Suberinite is a common constituent of facies I and sub-facies IIa coals. A distinctive form was recognised in the Bowmans Deposit, resembling fluorescing textinite/texto-ulminite (i.e. textinite Type A; ICCP, 1975). Initial concern regarding its correct identification prompted differentiation (i.e. suberinite "C"; Plate 5.11).

*Sub-maceral identifier:* **Suberinite "C"**
*Occurrence:* Woody sub-facies Ia coals, especially from the Bowmans Deposit.
*Size and shape:* Cell walls are generally thin and often devoid of vitrinite. Phytoclasts of various sizes (~50 to 500 μm) consistent with other suberinite varieties.
*Reflectance:* Very dull brown to black.
*Fluorescence colours:* Dull orange brown.
*Common associations:* Appears to be enriched in coals containing elongate, well gelified woody tissue (i.e. W2 fragments).
*Origin:* Unclear, possibly periderm associated with W2 wood particles.
*Distinction from other suberinite:* Fine cell walls, commonly empty cell lumens and low fluorescence.

## C1.2 TELOVITRINITE QUALIFIERS

Telovitrinite characteristics differ considerably and differentiation of phytoclasts was undertaken in line with phytoclasts size (i.e. groundmass or massive) and morphology. A very distinctive form of telovitrinite was also identified based on cell wall breakdown and the presence of very fine liptodetrinite

Qualifiers differ from the sub-macerals in that they represent an extension of the maceral identification, rather than a distinct sub-variety and therefore can be applied to multiple macerals.

### C1.2.1 Groundmass Telovitrinite Qualifiers

Groundmass telovitrinite includes smaller phytoclasts (i.e. < 250 μm) occurring within a detrovitrinite groundmass. Some of this material is macroscopically visible as groundmass tissue. Variations in size, morphology, freshness (i.e. extent of cell wall breakdown and pitting) and gelification were used to qualify groundmass telovitrinite as follows:

*Maceral qualifier*: **Type "B" and Type "D"**
*Size and shape:* Small telovitrinite phytoclasts (i.e. generally ≤ 50 μm) showing a high degree of cell wall breakdown and pitting and various morphologies. Type "B" is poorly gelified, while type "D" shows more advanced gelification (i.e. within the allowable maceral range).
*Common associations:* Most abundant in sub-facies Ib, less common in sub-facies Ia and Ic.
*Origin:* Tissue phytoclasts which have undergone significant biological and/or mechanical breakdown.
*Distinction from other telovitrinite:* Phytoclast size, pitted appearance and advanced cell wall breakdown.

*Maceral qualifier*: **Type "A' "and Type "E"**
*Size and shape:* Medium sized telovitrinite phytoclasts, commonly showing a strongly elongate form (i.e. ~50 to 250 μm) a fresh appearance. Type "B'" is poorly gelified, while type "E" shows more advanced gelification (i.e. within the allowable maceral range).
*Common associations:* Abundant in facies II with minor occurrence in sub-facies Ia (and rarely sub-facies Ib).
*Origin:* Tissue phytoclasts with very limited biological and/or mechanical breakdown.
*Distinction from other telovitrinite:* Phytoclast size, elongation and high degree of cell preservation.

### C1.2.2 Massive Telovitrinite Qualifiers

Massive telovitrinite includes large telovitrinite phytoclasts (i.e. exceeding 250 μm) occurring as single grains devoid of detrovitrinite, consistent with derivation from a larger phytoclast fragmented during grain mount preparation. Variations in gelification were used to further qualify massive telovitrinite.

*Maceral qualifier*: **Type "C" and Type "F"**
*Size and shape :* Large phytoclasts consisting entirely of telovitrinite. Cell walls are clearly evident and are generally fresh. Type "C'" is poorly gelified, while type "F" shows more advanced gelification (i.e. within the allowable maceral range).
*Common associations:* Restricted to wood-rich sub-facies Ia coals.
*Origin:* Macroscopically visible wood.
*Distinction from other telovitrinite:* Phytoclast size and occurrence in discrete grains devoid of detrovitrinite.

## C1.3 MICROTEXTURE QUALIFIERS

Two distinctive micro-textures were recognised relating to texto-ulminite and eu-ulminite phytoclasts (Plate 5.12) and a groundmass assemblage of predominantly well sorted corpogelinite, with some funginite and inertodetrinite (Plate 5.13).

*Microtexture qualifier*: **Type "T"**
*Size and shape:* Generally as massive phytoclasts (i.e. > 250 μm) and occasionally as groundmass tissue. Cell walls are evident, but show variable degrees of preservation, cell lumens are generally filled, are grainy in appearance and contain abundant fine liptinite.
*Common associations:* Restricted to sub-facies Ia coals from Bowmans in which elongate, well gelified, wood tissue (i.e. W2 particles) occur.
*Origin:* Associated with W2 woody fragments and possibly relates to subaerial tissue.
*Distinction from other telovitrinite:* Abundant fine liptinite, frequent cell wall breakdown and grainy texture.

*Microtexture qualifier*: **Type "B"**
*Size and shape:* An association of well sorted resistant maceral components including corpogelinite, funginite and inertodetrinite.
*Common associations:* Occurs within sub-facies Ia and Ib coals from the Bowmans Deposit. Similar occurrences have been noted elsewhere (ICCP, 1975; Cohen *et al.*, 1987).
*Origin:* Unclear, but possibly involves mechanical concentration.
*Distinction from other textures:* Abundant well sorted corpogelinite and elevated inertinite.

Appendix C2: Maceral data from point counts (sheet 1 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 |
| Sample | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 |
| Depth | 53.75 | 54.25 | 54.75 | 55.25 | 55.75 | 56.15 | 57.05 | 57.55 |
| Seam | F | F | F | F | F | F | G | G |
| Ply | F-3 | F-2 | F-2 | F-2 | F-1 | F-1 | G-6 | G-6 |
| Facies | Ib | IIb | IIb | IIb | Ib | Ib | Ic | Ic |
| **Examination** | | | | | | | | |
| Date | Jul-89 | Jul-89 | Nov-88 | Jul-89 | Jul-89 | Jul-89 | Nov-88 | Jul-89 |
| Coal counts | 323 | 317 | 313 | 307 | 316 | 309 | 324 | 321 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | 1.0 | - | - | - | - | - |
| Texto-ulminite | 25.4 | 13.2 | 27.5 | 30.6 | 11.1 | 20.4 | 4.3 | 6.2 |
| Eu-ulminite | 2.5 | 5.4 | 13.1 | 6.5 | 0.3 | 1.9 | 2.8 | 0.3 |
| Telocollinite | - | 0.3 | 1.0 | - | - | - | - | - |
| Attrinite | 5.3 | 0.3 | 1.0 | 4.2 | 52.2 | 23.9 | 15.4 | 17.8 |
| Densinite | 46.1 | 36.6 | 38.3 | 36.8 | 11.7 | 35.6 | 5.2 | 7.2 |
| Desmocollinite | 9.0 | 30.9 | 5.1 | 7.8 | 0.9 | 1.0 | - | 0.3 |
| Corpogelinite | 5.3 | 6.3 | 6.7 | 3.9 | 7.0 | 8.4 | 4.9 | 3.1 |
| Porigelinite | - | - | - | - | 0.3 | - | - | - |
| Eugelinite | - | - | 0.3 | - | - | - | - | - |
| *Total Vitrinite* | *93.5* | *93.1* | *93.9* | *89.9* | *83.5* | *91.3* | *32.7* | *34.9* |
| Sporinite | - | - | 0.3 | 0.3 | 0.9 | - | 3.4 | 2.5 |
| Cutinite | 0.3 | 0.3 | 2.2 | 4.9 | 0.3 | 0.6 | 4.9 | 4.4 |
| Resinite | 1.2 | - | - | 1.0 | 2.8 | 1.3 | 6.5 | 2.2 |
| Liptodetrinite | 2.2 | 3.2 | 0.6 | 1.3 | 7.3 | 4.9 | 33.0 | 32.4 |
| Alginite | - | - | 0.3 | - | - | - | 1.9 | - |
| Suberinite | 0.9 | 0.6 | 0.3 | 0.3 | 1.3 | 0.3 | 3.4 | 2.5 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 0.6 | 0.6 | - | 0.3 | 1.9 | - | 11.7 | 15.9 |
| *Total Liptinite* | *5.3* | *4.7* | *3.8* | *8.1* | *14.6* | *7.1* | *64.8* | *59.8* |
| Fusinite | 0.3 | 1.3 | 1.9 | 1.6 | - | 0.3 | 0.3 | 1.6 |
| Semifusinite | 0.6 | 0.6 | - | - | 0.9 | 0.6 | 0.6 | - |
| Funginite | - | 0.3 | - | - | 0.6 | - | 1.2 | 1.9 |
| Inertodetrinite | 0.3 | - | 0.3 | 0.3 | 0.3 | 0.6 | - | 1.9 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | - | 0.3 | - |
| *Total Inertinite* | *1.2* | *2.2* | *2.2* | *2.0* | *1.9* | *1.6* | *2.5* | *5.3* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | - | - | 3.4 |
| Massive telovitrinite | 19.2 | 1.6 | 2.2 | 1.6 | 0.3 | 6.1 | 3.1 | 2.2 |
| **Maceral Indices** | | | | | | | | |
| VPI | 31.6 | 21.8 | 48.9 | 43.2 | 14.9 | 27.0 | 25.6 | 20.6 |
| MTI | 68.9 | 8.3 | 5.3 | 4.4 | 2.8 | 27.5 | 43.5 | 33.3 |
| LPI | 53.3 | 23.1 | 83.3 | 83.3 | 42.5 | 31.8 | 37.8 | 26.2 |
| GI-1 | 53.2 | 72.6 | 54.7 | 53.8 | 11.3 | 31.4 | 13.4 | 16.1 |
| GI-2 | 46.1 | 78.3 | 40.4 | 41.7 | 44.8 | 39.4 | 42.9 | 41.9 |
| LEI | 26.9 | 40.1 | 83.4 | 72.2 | 34.0 | 43.4 | 41.3 | 32.9 |
| LAI | 13.3 | 15.4 | 0.0 | 4.2 | 15.0 | 0.0 | 22.1 | 36.2 |

Appendix C2: Maceral data from point counts (sheet 2 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 |
| Sample | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 |
| Depth | 58.05 | 58.45 | 59.05 | 59.45 | 60.05 | 60.55 | 61.05 | 61.55 |
| Seam | G | G | G | G | G | G | G | G |
| Ply | G-6 | G-5 | G-4 | G-4 | G-4 | G-4 | G-3 | G-3 |
| Facies | Ic | IIb | Ib (IVa) | Ib (IVa) | Ib | Ib | IIa | IIa |
| **Examination** | | | | | | | | |
| Date | Jul-89 | Jul-89 | Jul-89 | Jul-89 | Jul-89 | Jul-89 | Jul-89 | Aug-89 |
| Coal counts | 326 | 312 | 326 | 318 | 314 | 325 | 315 | 341 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | 0.3 | - | - | - | - |
| Texto-ulminite | 1.8 | 16.3 | 13.8 | 7.5 | 7.3 | 9.2 | 22.2 | 20.2 |
| Eu-ulminite | 0.9 | 3.8 | 1.8 | 0.9 | 1.0 | 1.5 | 3.8 | 0.6 |
| Telocollinite | - | - | - | - | - | - | - | - |
| Attrinite | 9.5 | 5.4 | 22.4 | 32.7 | 32.5 | 36.3 | 21.3 | 15.0 |
| Densinite | 13.8 | 34.3 | 22.1 | 11.0 | 11.8 | 11.4 | 22.9 | 37.0 |
| Desmocollinite | 4.9 | 17.3 | 6.7 | 1.3 | 3.8 | 3.1 | 9.8 | 8.2 |
| Corpogelinite | 5.5 | 4.2 | 4.0 | 2.8 | 6.4 | 5.5 | 2.2 | 2.6 |
| Porigelinite | - | - | 0.3 | - | - | 0.3 | 0.6 | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *36.5* | *81.4* | *71.2* | *56.6* | *62.7* | *67.4* | *82.9* | *83.6* |
| Sporinite | 2.5 | 1.0 | 1.5 | 1.3 | 0.6 | 1.5 | 1.6 | 1.5 |
| Cutinite | 2.1 | 0.6 | 0.6 | 0.3 | 0.6 | - | - | 0.6 |
| Resinite | 4.6 | 0.3 | 1.8 | 1.3 | 4.5 | 3.1 | 2.2 | 1.5 |
| Liptodetrinite | 35.3 | 8.0 | 11.0 | 14.8 | 21.3 | 18.5 | 10.5 | 7.0 |
| Alginite | - | - | - | - | - | 0.3 | - | - |
| Suberinite | 3.1 | 1.3 | 4.3 | 1.6 | 4.8 | 3.1 | 0.6 | 5.0 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 12.0 | 2.9 | 3.7 | 2.8 | 2.5 | 4.0 | 1.3 | 0.3 |
| *Total Liptinite* | *59.5* | *14.1* | *23.0* | *22.0* | *34.4* | *30.5* | *16.2* | *15.8* |
| Fusinite | 0.3 | 2.6 | 1.2 | - | 0.3 | - | - | - |
| Semifusinite | 1.2 | 0.6 | - | 1.3 | - | 0.3 | 0.6 | 0.6 |
| Funginite | 1.5 | 0.3 | 0.6 | 0.6 | 1.3 | 0.9 | 0.3 | - |
| Inertodetrinite | 0.9 | 1.0 | 1.2 | 0.3 | 1.0 | 0.9 | - | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | 2.8 | 19.2 | 0.3 | - | - | - |
| *Total Inertinite* | *4.0* | *4.5* | *5.8* | *21.4* | *2.9* | *2.2* | *1.0* | *0.6* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | 2.1 | - | - | - | 0.3 | - | - | 0.6 |
| Massive telovitrinite | 0.9 | 5.1 | 3.7 | 2.8 | 1.6 | 3.7 | 6.3 | 6.7 |
| **Maceral Indices** | | | | | | | | |
| VPI | 8.9 | 26.1 | 23.4 | 16.4 | 14.7 | 17.5 | 32.5 | 25.7 |
| MTI | 33.3 | 25.4 | 23.5 | 32.1 | 19.2 | 34.3 | 24.4 | 32.4 |
| LPI | 25.8 | 28.6 | 42.9 | 23.0 | 33.0 | 30.2 | 29.8 | 54.7 |
| GI-1 | 42.2 | 60.5 | 35.2 | 15.8 | 20.9 | 18.0 | 39.8 | 44.6 |
| GI-2 | 63.2 | 62.1 | 50.3 | 45.8 | 51.0 | 48.2 | 49.0 | 48.1 |
| LEI | 33.9 | 39.9 | 33.6 | 40.8 | 34.1 | 36.6 | 42.3 | 31.9 |
| LAI | 25.2 | 25.7 | 19.0 | 14.8 | 8.0 | 15.1 | 8.5 | 1.9 |

Appendix C2: Maceral data from point counts (sheet 3 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 |
| Sample | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| Depth | 62.05 | 62.60 | 63.10 | 63.55 | 64.00 | 66.75 | 67.25 | 67.70 |
| Seam | G | G | G | G | G | H | H | H |
| Ply | G-3 | G-2 | G-2 | G-2 | G-1 | H-2 | H-2 | H-1b |
| Facies | IIa | Ia | Ia | Ia | III | Ib | Ib | Ic |
| **Examination** | | | | | | | | |
| Date | Aug-89 | Aug-89 | Aug-89 | Aug-89 | Aug-89 | Jul-89 | Jul-89 | Jul-89 |
| Coal counts | 307 | 312 | 311 | 340 | 310 | 216 | 315 | 317 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | - |
| Texto-ulminite | 8.1 | 24.0 | 11.9 | 22.6 | 9.4 | 43.5 | 17.5 | 17.4 |
| Eu-ulminite | 8.1 | 6.4 | 9.6 | 2.1 | 12.6 | 0.9 | 1.6 | 0.9 |
| Telocollinite | - | - | - | - | 7.4 | - | - | - |
| Attrinite | - | 11.9 | 23.5 | 22.4 | 13.5 | 2.8 | 30.5 | 21.8 |
| Densinite | 39.1 | 30.8 | 18.0 | 24.4 | 41.3 | 25.5 | 21.6 | 3.2 |
| Desmocollinite | 27.0 | 7.7 | 4.2 | 7.4 | 2.9 | 4.6 | 0.3 | - |
| Corpogelinite | 9.4 | 4.2 | 4.5 | 3.8 | 0.6 | 10.6 | 7.3 | 5.7 |
| Porigelinite | - | 1.0 | 0.6 | - | 0.3 | - | 1.3 | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *91.9* | *85.9* | *72.3* | *82.6* | *88.1* | *88.0* | *80.0* | *48.9* |
| Sporinite | 0.7 | 0.6 | 1.3 | 1.2 | 1.6 | - | 0.6 | 1.3 |
| Cutinite | 1.3 | - | 0.6 | 0.6 | 1.3 | - | - | 1.6 |
| Resinite | 1.0 | 1.9 | 2.6 | 1.5 | 2.9 | 1.4 | 3.2 | 3.8 |
| Liptodetrinite | 3.3 | 7.1 | 17.7 | 9.1 | 5.5 | 5.1 | 12.4 | 36.6 |
| Alginite | - | - | 0.3 | - | 0.3 | - | - | - |
| Suberinite | 1.0 | 3.8 | 2.6 | 4.4 | - | 2.8 | 3.2 | 3.8 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | 0.3 | 1.0 | - | - | 1.4 | 0.3 | 2.5 |
| *Total Liptinite* | *7.2* | *13.8* | *26.0* | *16.8* | *11.6* | *10.6* | *19.7* | *49.5* |
| Fusinite | - | - | 0.3 | - | - | - | - | - |
| Semifusinite | 0.7 | - | - | 0.6 | - | 0.9 | - | 0.6 |
| Funginite | 0.3 | - | 0.3 | - | 0.3 | 0.5 | 0.3 | 0.3 |
| Inertodetrinite | - | 0.3 | 1.0 | - | - | - | - | 0.6 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | - | - | - |
| *Total Inertinite* | *1.0* | *0.3* | *1.6* | *0.6* | *0.3* | *1.4* | *0.3* | *1.6* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | 0.3 | 0.3 | - | - | - | 0.6 |
| Massive telovitrinite | 1.6 | 15.4 | 11.9 | 13.5 | 6.1 | 22.2 | 7.3 | 12.3 |
| **Maceral Indices** | | | | | | | | |
| VPI | 19.8 | 37.7 | 32.1 | 31.3 | 33.7 | 57.5 | 26.7 | 42.3 |
| MTI | 10.0 | 50.5 | 55.2 | 54.8 | 20.9 | 50.0 | 38.3 | 67.2 |
| LPI | 54.5 | 47.6 | 29.5 | 45.6 | 52.8 | 45.0 | 36.1 | 22.1 |
| GI-1 | 70.4 | 46.1 | 29.4 | 36.6 | 41.0 | 52.9 | 21.8 | 7.2 |
| GI-2 | 78.0 | 45.1 | 47.9 | 45.5 | 52.5 | 28.4 | 38.9 | 30.8 |
| LEI | 50.3 | 30.7 | 41.6 | 36.3 | 51.6 | 24.3 | 35.0 | 41.6 |
| LAI | 0.0 | 2.4 | 3.8 | 0.0 | 0.0 | 15.0 | 1.6 | 5.4 |

Appendix C2: Maceral data from point counts (sheet 4 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V714 | V714 | V714 | V714 | V706 | V706 | V706 | V706 |
| Sample | 71 | 72 | 73 | 74 | L 540 | L 541 | L 542 | L 543 |
| Depth | 68.25 | 68.75 | 69.25 | 69.65 | 54.35 | 55.10 | 55.35 | 55.65 |
| Seam | H | H | H | H | F | F | F | F |
| Ply | H-1b | H-1b | H-1b | H-1a | F-5 | F-5 | F-5 | F-5 |
| Facies | Ia | Ia | Ia | Ia | III | III | III | III |
| **Examination** | | | | | | | | |
| Date | Jul-89 | Jul-89 | Jul-89 | Jul-89 | Aug-89 | Aug-89 | Aug-89 | Aug-89 |
| Coal counts | 317 | 319 | 308 | 320 | 306 | 308 | 307 | 316 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | - |
| Texto-ulminite | 41.0 | 43.9 | 46.1 | 33.4 | 0.7 | 1.9 | 5.2 | 2.2 |
| Eu-ulminite | 4.1 | 8.2 | 17.9 | 6.3 | 0.7 | 1.0 | 1.0 | 0.3 |
| Telocollinite | - | - | - | 0.6 | - | - | - | 0.3 |
| Attrinite | 12.9 | 15.7 | 10.7 | 4.4 | 57.2 | 1.9 | 10.1 | 0.3 |
| Densinite | 15.8 | 13.5 | 5.5 | 25.3 | 8.5 | 36.4 | 33.9 | 9.8 |
| Desmocollinite | 10.1 | 3.1 | 6.2 | 8.4 | - | 39.3 | 30.3 | 70.3 |
| Corpogelinite | 1.6 | 1.9 | 3.6 | 11.3 | 1.6 | 4.9 | 1.3 | 1.3 |
| Porigelinite | - | 0.3 | 0.3 | - | - | - | - | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *85.5* | *86.5* | *90.3* | *89.7* | *68.6* | *85.4* | *81.8* | *84.5* |
| Sporinite | - | 0.9 | 0.3 | 0.3 | 3.3 | 1.0 | 1.0 | 1.9 |
| Cutinite | 0.6 | 0.9 | 1.6 | 1.9 | 1.3 | 2.9 | 2.3 | 2.8 |
| Resinite | 4.1 | 0.6 | 0.6 | - | 2.6 | 0.6 | 2.3 | 0.3 |
| Liptodetrinite | 4.7 | 6.0 | 4.2 | 3.8 | 19.3 | 3.2 | 4.6 | 2.8 |
| Alginite | - | - | - | - | 0.7 | 0.3 | 0.3 | 1.6 |
| Suberinite | 1.6 | 4.4 | 1.0 | 3.8 | 1.6 | 2.6 | 1.6 | 0.3 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 3.2 | 0.3 | 1.6 | 0.3 | 0.7 | - | - | - |
| *Total Liptinite* | *14.2* | *13.2* | *9.4* | *10.0* | *29.4* | *10.7* | *12.1* | *9.8* |
| Fusinite | - | - | - | - | - | 1.3 | 2.0 | 0.9 |
| Semifusinite | - | - | - | - | 0.7 | 0.3 | 0.3 | 0.6 |
| Funginite | 0.3 | 0.3 | 0.3 | 0.3 | 0.7 | - | 0.3 | 0.3 |
| Inertodetrinite | - | - | - | - | 0.7 | 0.6 | 2.0 | 2.8 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | 1.6 | 1.6 | 0.9 |
| *Total Inertinite* | *0.3* | *0.3* | *0.3* | *0.3* | *2.0* | *3.9* | *6.2* | *5.7* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | 0.6 | 0.9 | 1.6 | 1.6 | 0.7 | 1.0 | 0.7 | - |
| Massive telovitrinite | 43.2 | 49.2 | 61.7 | 36.6 | 0.0 | 0.0 | 2.9 | 0.3 |
| **Maceral Indices** | | | | | | | | |
| VPI | 53.8 | 61.7 | 74.1 | 51.4 | 2.0 | 3.6 | 7.7 | 3.4 |
| MTI | 95.8 | 94.6 | 96.4 | 90.7 | 0.0 | 0.0 | 47.4 | 11.1 |
| LPI | 57.1 | 53.7 | 45.8 | 61.3 | 33.0 | 69.7 | 62.2 | 71.0 |
| GI-1 | 46.7 | 31.1 | 40.3 | 55.4 | 7.3 | 74.1 | 63.7 | 93.5 |
| GI-2 | 38.2 | 28.4 | 31.1 | 40.3 | 50.4 | 97.6 | 84.6 | 133.3 |
| LEI | 17.1 | 30.2 | 26.2 | 25.5 | 48.5 | 45.8 | 43.6 | 79.1 |
| LAI | 28.6 | 2.4 | 20.8 | 3.2 | 2.3 | 0.0 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 5 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V706 | V706 | V706 | V706 | V706 | V706 | V704 | V704 |
| Sample | L 544D | L544N | L 545 | L 546 | L 547 | L 548 | 1 | 2 |
| Depth | 55.85 | 55.85 | 56.05 | 56.60 | 57.00 | 57.20 | 58.55 | 58.75 |
| Seam | F | F | F | F | F | F | F | F |
| Ply | F-4 | F-4 | F-2 | F-2 | F-2 | F-1 | F-4 | F-3 |
| Facies | IV | IVa | IIb | IIb | IIb | Ib | IVa | III/II/I |
| **Examination** | | | | | | | | |
| Date | Aug-89 | Aug-89 | Aug-89 | Aug-89 | Aug-89 | Aug-89 | Aug-87 | Aug-87 |
| Coal counts | 311 | 311 | 328 | 304 | 307 | 323 | 141 | 299 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | - |
| Texto-ulminite | 21.9 | - | 14.9 | 28.0 | 10.1 | 1.5 | 3.5 | 4.3 |
| Eu-ulminite | 2.3 | - | 12.5 | 8.2 | 7.8 | 4.0 | 2.8 | 1.7 |
| Telocollinite | - | - | - | 0.3 | - | - | 2.8 | - |
| Attrinite | - | - | - | 4.9 | 5.2 | 29.4 | - | 19.7 |
| Densinite | 16.4 | - | 18.0 | 28.9 | 49.5 | 39.0 | 9.2 | 46.5 |
| Desmocollinite | 55.0 | 0.3 | 41.2 | 12.8 | 12.7 | 1.9 | 53.9 | 12.0 |
| Corpogelinite | 2.3 | - | 4.3 | 5.3 | 6.5 | 6.2 | - | 4.7 |
| Porigelinite | 0.3 | - | - | - | - | - | - | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *98.1* | *0.3* | *90.9* | *88.5* | *91.9* | *82.0* | *72.3* | *89.0* |
| Sporinite | - | - | - | - | - | 2.5 | 0.7 | 0.3 |
| Cutinite | - | - | 3.0 | 4.9 | 2.3 | 1.5 | - | 0.3 |
| Resinite | - | - | - | - | 1.3 | 2.5 | 2.8 | 4.7 |
| Liptodetrinite | 0.3 | 0.3 | 1.5 | 1.6 | 3.6 | 9.6 | 2.1 | 3.3 |
| Alginite | - | - | - | - | 0.3 | 0.3 | - | - |
| Suberinite | - | - | - | - | 0.3 | 0.3 | 0.7 | 0.7 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | - | - | - | - | - | - | - |
| *Total Liptinite* | *0.3* | *0.3* | *4.6* | *6.6* | *7.8* | *16.7* | *6.4* | *9.4* |
| Fusinite | 1.3 | 25.4 | 3.0 | 4.6 | - | - | 1.4 | 0.7 |
| Semifusinite | - | - | 0.3 | 0.3 | 0.3 | 0.3 | 1.4 | - |
| Funginite | - | - | 0.6 | - | - | 0.6 | - | 0.3 |
| Inertodetrinite | 0.3 | - | 0.6 | - | - | 0.3 | - | 0.3 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | 74.0 | - | - | - | - | 18.4 | 0.3 |
| *Total Inertinite* | *1.6* | *99.4* | *4.6* | *4.9* | *0.3* | *1.2* | *21.3* | *1.7* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | - | - | - |
| Massive telovitrinite | 5.5 | 0.0 | 6.7 | 2.3 | 3.3 | 0.0 | 0.7 | 0.0 |
| **Maceral Indices** | | | | | | | | |
| VPI | 25.3 | 0.0 | 31.7 | 43.9 | 21.0 | 7.3 | 12.7 | 7.1 |
| MTI | 22.7 | 0.0 | 24.4 | 6.3 | 18.2 | 0.0 | 7.7 | 0.0 |
| LPI | 0.0 | 0.0 | 66.7 | 75.0 | 54.2 | 42.6 | 66.7 | 64.3 |
| GI-1 | 88.5 | 100.0 | 84.8 | 58.6 | 55.6 | 30.8 | 92.7 | |
| GI-2 | 96.4 | 150.0 | 89.1 | 49.2 | 59.1 | 51.8 | 124.1 | |
| LEI | 50.0 | 50.0 | 83.3 | 87.5 | 56.5 | 54.8 | 28.3 | |
| LAI | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 6 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 |
| Sample | 3 | 28 | 29 | 30 | 31 | 32 | 33 | 34 |
| Depth | 59.05 | 59.8 | 60.25 | 60.75 | 63.15 | 63.70 | 64.40 | 64.80 |
| Seam | F | F | F | F | G | G | G | G |
| Ply | F-3 | F-2 | F-2 | F-1 | G-5 | G-5 | G-4 | G-4 |
| Facies | Ia | IIb | IIb | Ib | IIb | IIa | Ib | Ib |
| **Examination** | | | | | | | | |
| Date | Aug-87 | Jul-87 | Jul-87 | Aug-87 | Jul-87 | Jul-87 | Jul-87 | Aug-87 |
| Coal counts | 309 | 266 | 478 | 285 | 274 | 307 | 302 | 321 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | - |
| Texto-ulminite | 30.4 | 16.9 | 15.5 | 9.8 | 12.0 | 12.7 | 3.0 | 6.2 |
| Eu-ulminite | 26.2 | 4.9 | 1.9 | 2.5 | 4.7 | 4.6 | 1.3 | - |
| Telocollinite | 0.3 | 0.4 | 0.4 | - | 3.6 | 1.0 | 0.3 | - |
| Attrinite | 6.1 | 21.1 | 34.3 | 43.9 | 3.6 | 14.0 | 37.1 | 54.8 |
| Densinite | 22.0 | 35.7 | 28.2 | 18.2 | 36.1 | 37.8 | 24.2 | 14.0 |
| Desmocollinite | 1.0 | 1.9 | 2.7 | 1.1 | 19.0 | 4.6 | 4.3 | 0.9 |
| Corpogelinite | 4.5 | 7.1 | 5.2 | 10.2 | 4.4 | 5.5 | 1.0 | 3.4 |
| Porigelinite | 1.0 | - | 0.2 | 0.4 | 0.4 | - | 0.3 | 0.3 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *91.6* | *88.0* | *88.5* | *86.0* | *83.9* | *80.1* | *71.5* | *79.8* |
| Sporinite | 0.3 | 0.8 | 0.2 | - | 0.4 | 0.7 | 1.3 | 1.9 |
| Cutinite | - | 3.0 | 2.7 | 0.4 | 0.7 | 0.3 | - | 1.2 |
| Resinite | 1.9 | 0.8 | 1.7 | 3.9 | 1.5 | 3.3 | 6.0 | 0.9 |
| Liptodetrinite | 1.9 | 3.0 | 1.5 | 5.3 | 4.4 | 5.5 | 16.2 | 9.0 |
| Alginite | - | - | - | - | 0.7 | - | 0.7 | - |
| Suberinite | 0.6 | - | 1.0 | 2.5 | - | 3.9 | 2.6 | 5.3 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | - | - | 1.4 | - | 0.7 | - | 0.3 |
| *Total Liptinite* | *4.9* | *7.5* | *7.1* | *13.3* | *7.7* | *14.3* | *26.8* | *18.7* |
| Fusinite | 1.0 | 3.8 | 3.3 | - | 5.5 | 2.9 | 0.7 | - |
| Semifusinite | 1.0 | 0.4 | 0.2 | 0.4 | 0.7 | - | 0.3 | 0.3 |
| Funginite | - | - | - | 0.4 | 0.4 | 1.0 | 0.3 | 0.9 |
| Inertodetrinite | 0.6 | 0.4 | 0.8 | - | 1.8 | 1.6 | 0.3 | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | 1.0 | - | - | - | - | - | - | 0.3 |
| *Total Inertinite* | *3.6* | *4.5* | *4.4* | *0.7* | *8.4* | *5.5* | *1.7* | *1.6* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | - | - | - |
| Massive telovitrinite | 46.9 | 0.0 | 2.5 | 1.1 | 1.5 | 2.6 | 0.0 | 0.6 |
| **Maceral Indices** | | | | | | | | |
| VPI | 66.2 | 27.4 | 21.4 | 16.3 | 25.8 | 24.5 | 6.6 | 8.2 |
| MTI | 82.4 | 0.0 | 14.1 | 8.6 | 7.1 | 14.3 | 0.0 | 10.0 |
| LPI | 60.0 | 60.0 | 79.4 | 55.9 | 42.9 | 59.5 | 39.5 | 50.8 |
| GI-1 | 41.3 | 34.0 | 26.3 | 16.8 | 63.1 | 41.9 | 25.6 | 12.2 |
| GI-2 | 34.1 | 42.6 | 44.8 | 45.6 | 68.9 | 48.6 | 54.8 | 47.9 |
| LEI | 27.2 | 70.1 | 51.9 | 22.8 | 52.6 | 26.6 | 38.0 | 41.2 |
| LAI | 0.0 | 0.0 | 0.0 | 11.8 | 0.0 | 4.8 | 0.0 | 1.7 |

Appendix C2: Maceral data from point counts (sheet 7 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 |
| Sample | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
| Depth | 65.55 | 65.95 | 66.40 | 67.10 | 67.65 | 68.20 | 68.65 | 69.35 |
| Seam | G | G | G | G | G | G | G | G |
| Ply | G-4 | G-4 | G-4 | G-3 | G-3 | G-3 | G-2 | G-1 |
| Facies | Ib | Ib | Ib | IIa | Ib | Ib | Ia | III |
| **Examination** | | | | | | | | |
| Date | Jul-87 | Jul-87 | Aug-87 | Jul-87 | Aug-87 | Jul-/87 | Jan-87 | Jul-87 |
| Coal counts | 309 | 298 | 331 | 327 | 307 | 291 | 323 | 274 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | - |
| Texto-ulminite | 11.3 | 6.0 | 13.6 | 16.5 | 5.9 | 29.6 | 9.6 | 15.0 |
| Eu-ulminite | 2.6 | 0.3 | 4.5 | 7.3 | 1.3 | 4.5 | 6.5 | 17.9 |
| Telocollinite | 1.3 | 0.3 | - | 0.3 | 0.3 | 1.0 | 2.5 | 5.1 |
| Attrinite | 28.5 | 40.9 | 21.5 | 10.4 | 12.1 | 3.1 | 21.7 | 0.4 |
| Densinite | 30.4 | 18.5 | 29.0 | 34.3 | 43.6 | 24.4 | 22.6 | 17.9 |
| Desmocollinite | 8.4 | 2.7 | 9.1 | 13.1 | 15.6 | 20.3 | 12.4 | 29.6 |
| Corpogelinite | 2.9 | 3.7 | 6.0 | 6.4 | 6.2 | 2.7 | 4.6 | 4.0 |
| Porigelinite | 1.0 | - | - | 0.3 | - | 0.3 | - | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *86.4* | *72.5* | *83.7* | *88.7* | *85.0* | *85.9* | *79.9* | *89.8* |
| Sporinite | 1.0 | 3.4 | 1.5 | 0.6 | 1.0 | 1.4 | 2.5 | 1.1 |
| Cutinite | - | 0.3 | - | 0.3 | 0.3 | - | - | - |
| Resinite | 1.9 | 3.7 | 2.7 | 1.8 | 3.9 | 3.1 | 5.0 | 1.1 |
| Liptodetrinite | 5.2 | 15.4 | 5.7 | 3.7 | 4.9 | 5.8 | 10.2 | 5.8 |
| Alginite | 0.3 | 0.3 | - | - | - | - | - | - |
| Suberinite | 4.9 | 2.0 | 3.0 | 4.0 | 2.3 | 2.7 | 1.9 | 0.4 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | 0.7 | - | - | - | - | - | - |
| *Total Liptinite* | *13.3* | *25.8* | *13.0* | *10.4* | *12.4* | *13.1* | *19.5* | *8.4* |
| Fusinite | 0.3 | 0.7 | 0.6 | 0.6 | 0.3 | - | 0.3 | 0.4 |
| Semifusinite | - | - | - | - | 0.3 | 0.3 | - | - |
| Funginite | - | 0.3 | 1.8 | 0.3 | 1.3 | 0.7 | 0.3 | - |
| Inertodetrinite | - | 0.7 | 0.3 | - | 0.7 | - | - | 1.5 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | 0.6 | - | - | - | - | - |
| *Total Inertinite* | *0.3* | *1.7* | *3.3* | *0.9* | *2.6* | *1.0* | *0.6* | *1.8* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | - | - | - |
| Massive telovitrinite | 2.6 | 1.7 | 3.0 | 3.7 | 0.7 | 7.2 | 5.0 | 1.1 |
| **Maceral Indices** | | | | | | | | |
| VPI | 18.4 | 9.8 | 23.3 | 29.5 | 9.5 | 42.3 | 24.7 | 44.3 |
| MTI | 17.0 | 25.0 | 16.7 | 15.2 | 8.7 | 20.6 | 26.7 | 2.9 |
| LPI | 61.0 | 38.7 | 55.8 | 64.7 | 60.5 | 55.3 | 47.6 | 30.4 |
| GI-1 | 35.5 | 19.8 | 40.0 | 52.6 | 52.7 | 68.1 | 42.2 | 80.5 |
| GI-2 | 54.6 | 50.4 | 53.4 | 56.5 | 66.5 | 57.7 | 62.1 | 78.9 |
| LEI | 29.8 | 45.7 | 34.2 | 27.0 | 30.8 | 33.3 | 39.2 | 48.0 |
| LAI | 0.0 | 2.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 8 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | V704 | V704 | V704 | V672 | V672 | S12 | S12 | S12 |
| Sample | 43 | 44 | 45 | L 500 | L 513 | 101 | 102 | 103 |
| Depth | 69.65 | 72.25 | 72.70 | 34.90 | 41.25 | 0.30 | 0.70 | 1.00 |
| Seam | G | H | H | F | G | G | G | G |
| Ply | G-1 | H-2 | H-2 | F-4 | G-3 | G-6 | G-6 | G-6 |
| Facies | III | Ib | Ib | IVb | IIa | Ia | Ia | Ia |
| **Examination** | | | | | | | | |
| Date | Jul-87 | Jul-87 | Jul-87 | Sep-89 | Jul-89 | Oct-88 | Oct-88 | Oct-88 |
| Coal counts | 291 | 334 | 258 | 254 | 306 | 334 | 355 | 344 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | 0.4 | - | - | - | - |
| Texto-ulminite | 13.1 | 21.3 | 20.2 | 11.0 | 24.8 | 25.1 | 27.9 | 21.2 |
| Eu-ulminite | 10.0 | 2.4 | 5.0 | 3.9 | 8.5 | 3.0 | 7.6 | 1.7 |
| Telocollinite | 5.8 | - | - | - | - | 0.6 | 0.3 | 0.3 |
| Attrinite | 5.2 | 35.6 | 48.1 | 46.1 | 27.5 | 30.8 | 27.6 | 41.3 |
| Densinite | 29.2 | 15.3 | 7.4 | 18.5 | 25.8 | 12.6 | 11.5 | 10.5 |
| Desmocollinite | 26.1 | 2.7 | - | 3.1 | 1.0 | 2.1 | - | 1.5 |
| Corpogelinite | 0.7 | 7.2 | 5.4 | 2.8 | 5.6 | 5.7 | 4.5 | 4.1 |
| Porigelinite | - | 1.2 | - | - | - | 2.1 | 0.6 | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *90.0* | *85.6* | *86.0* | *85.8* | *93.1* | *82.0* | *80.0* | *80.5* |
| Sporinite | 0.7 | 0.3 | 0.4 | 1.6 | - | 1.8 | 2.8 | 1.5 |
| Cutinite | - | 0.3 | 0.4 | 2.0 | 0.3 | 2.4 | 1.7 | 1.2 |
| Resinite | 1.7 | 2.4 | 2.7 | 2.0 | 1.0 | 2.4 | 3.7 | 0.9 |
| Liptodetrinite | 4.1 | 5.7 | 6.6 | - | 2.9 | 5.1 | 7.9 | 9.6 |
| Alginite | - | - | - | - | - | - | 0.3 | 0.6 |
| Suberinite | 0.7 | 4.2 | 3.1 | 6.7 | 0.7 | 3.3 | 1.4 | 0.9 |
| Fluorinite | 0.7 | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 1.0 | 0.3 | 0.4 | 0.4 | 0.3 | 1.8 | 1.7 | 2.3 |
| *Total Liptinite* | *8.9* | *13.2* | *13.6* | *12.6* | *5.2* | *16.8* | *19.4* | *16.9* |
| Fusinite | - | - | - | - | 1.0 | - | - | 0.9 |
| Semifusinite | 0.3 | 0.6 | - | 0.4 | - | 0.3 | - | 0.6 |
| Funginite | - | 0.6 | 0.4 | 0.8 | - | 0.3 | 0.3 | 0.3 |
| Inertodetrinite | 0.3 | - | - | 0.4 | 0.7 | 0.6 | 0.3 | 0.9 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | 0.3 | - | - | - | - | - | - | - |
| *Total Inertinite* | *1.0* | *1.2* | *0.4* | *1.6* | *1.6* | *1.2* | *0.6* | *2.6* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | 1.5 | 1.4 | 0.6 |
| Massive telovitrinite | 0.7 | 6.0 | 14.3 | 6.3 | 9.2 | 22.2 | 32.1 | 16.9 |
| **Maceral Indices** | | | | | | | | |
| VPI | 32.3 | 30.6 | 31.3 | 18.5 | 38.1 | 38.7 | 47.7 | 30.4 |
| MTI | 2.4 | 25.3 | 56.9 | 41.0 | 27.5 | 77.1 | 89.8 | 72.5 |
| LPI | 42.9 | 55.8 | 50.0 | 100.0 | 40.0 | 66.0 | 55.6 | 34.0 |
| GI-1 | 67.4 | 19.9 | 7.5 | 19.0 | 26.1 | 19.1 | 15.5 | 13.3 |
| GI-2 | 75.4 | 40.5 | 38.3 | 47.6 | 37.5 | 37.0 | 32.3 | 39.0 |
| LEI | 31.0 | 26.6 | 30.4 | 28.8 | 34.7 | 31.7 | 38.0 | 44.1 |
| LAI | 23.8 | 2.3 | 2.9 | 3.2 | 6.7 | 12.0 | 9.5 | 16.0 |

Appendix C2: Maceral data from point counts (sheet 9 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | S12 | S12 | S12 | S12 | S12 | S12 | S12 | S12 |
| Sample | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 |
| Depth | 1.50 | 1.90 | 2.25 | 2.65 | 3.10 | 3.50 | 3.95 | 4.65 |
| Seam | G | G | G | G | G | G | G | G |
| Ply | G-5 | G-5 | G-4 | G-4 | G-4 | G-4 | G-4 | G-3 |
| Facies | IIa | IIa | Ib | Ib | Ib | Ib | Ib | IIa |
| **Examination** | | | | | | | | |
| Date | Oct-88 | Oct-88 | Nov-88 | Nov-88 | Oct-88 | Nov-88 | Nov-88 | Nov-88 |
| Coal counts | 346 | 336 | 305 | 317 | 286 | 311 | 323 | 309 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | 0.3 | 1.3 | 0.6 | 0.3 | 0.3 | 0.9 | - |
| Texto-ulminite | 6.9 | 8.9 | 32.1 | 17.7 | 21.3 | 19.0 | 57.3 | 21.7 |
| Eu-ulminite | 4.0 | 2.7 | 1.3 | 2.2 | 3.1 | 5.8 | 12.4 | 7.8 |
| Telocollinite | - | 0.3 | - | - | - | - | 0.3 | - |
| Attrinite | 51.4 | 37.8 | 44.6 | 41.0 | 30.1 | 26.7 | 6.8 | 18.4 |
| Densinite | 13.3 | 19.3 | 2.0 | 16.1 | 14.7 | 21.9 | 10.2 | 31.4 |
| Desmocollinite | 4.0 | 2.7 | 0.7 | 1.9 | 5.6 | 2.6 | 5.3 | 4.5 |
| Corpogelinite | 1.4 | 4.8 | 3.9 | 8.2 | 10.5 | 4.2 | 2.5 | 4.5 |
| Porigelinite | 1.2 | 0.9 | 1.0 | 0.3 | - | - | - | - |
| Eugelinite | - | - | - | 0.6 | - | - | - | - |
| *Total Vitrinite* | *82.4* | *77.7* | *86.9* | *88.6* | *85.7* | *80.4* | *95.7* | *88.3* |
| Sporinite | 2.3 | 0.9 | - | 0.3 | 1.4 | 2.6 | 0.3 | 0.3 |
| Cutinite | - | 0.9 | 0.3 | 0.9 | 0.3 | 0.3 | - | 0.6 |
| Resinite | 1.2 | 1.8 | 0.7 | 1.9 | 2.8 | 1.9 | 0.6 | 1.0 |
| Liptodetrinite | 4.9 | 8.6 | 8.9 | 4.7 | 5.6 | 9.6 | 1.5 | 5.2 |
| Alginite | - | - | 0.7 | - | 0.3 | 1.6 | - | - |
| Suberinite | 2.0 | 1.5 | 1.0 | 1.9 | 2.8 | 1.3 | 1.5 | 2.3 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 0.6 | - | 1.0 | - | - | 0.6 | - | 1.0 |
| *Total Liptinite* | *11.0* | *13.7* | *12.5* | *9.8* | *13.3* | *18.0* | *4.0* | *10.4* |
| Fusinite | 3.8 | 5.4 | - | 0.3 | - | - | 0.3 | - |
| Semifusinite | 0.6 | 0.9 | 0.7 | 0.6 | - | - | - | 0.3 |
| Funginite | 0.3 | 0.6 | - | 0.6 | 0.3 | 1.0 | - | 1.0 |
| Inertodetrinite | 1.7 | 1.2 | - | - | 0.3 | 0.3 | - | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | 0.3 | 0.6 | - | - | 0.3 | 0.3 | - | - |
| *Total Inertinite* | *6.6* | *8.6* | *0.7* | *1.6* | *1.0* | *1.6* | *0.3* | *1.3* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | - | - | - |
| Massive telovitrinite | 0.9 | 0.9 | 28.9 | 11.7 | 17.8 | 14.1 | 65.9 | 22.3 |
| **Maceral Indices** | | | | | | | | |
| VPI | 13.8 | 16.9 | 42.4 | 25.8 | 33.0 | 32.9 | 76.1 | 35.1 |
| MTI | 7.9 | 7.3 | 83.0 | 56.9 | 71.8 | 56.4 | 93.0 | 75.8 |
| LPI | 52.8 | 37.0 | 22.9 | 51.6 | 57.9 | 44.4 | 61.5 | 44.8 |
| GI-1 | 16.3 | 21.3 | 4.4 | 17.5 | 26.3 | 26.9 | 46.8 | 37.5 |
| GI-2 | 51.5 | 48.2 | 31.4 | 41.6 | 43.7 | 41.3 | 25.3 | 42.9 |
| LEI | 43.7 | 44.8 | 43.6 | 37.5 | 37.3 | 52.0 | 27.5 | 34.7 |
| LAI | 5.6 | 0.0 | 8.6 | 0.0 | 0.0 | 3.7 | 0.0 | 10.3 |

Appendix C2: Maceral data from point counts (sheet 10 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | S12 | S12 | S12 | V690 | V690 | V695 | V674 | V674 |
| Sample | 112 | 113 | 114 | L 154 | L156 | L 376 | L534 | L535 |
| Depth | 5.05 | 5.40 | 5.85 | 45.10 | 50.80 | 48.00 | 32.40 | 32.75 |
| Seam | G | G | G | F | G | G | G | G |
| Ply | G-3 | G-2 | G-1 | F-5 | G-4 | G-1 | G-2 | G-1 |
| Facies | IIa | Ia | III | III | Ic | IIa | III | III |
| **Examination** | | | | | | | | |
| Date | Nov-88 | Nov-88 | Nov-88 | Sep-89 | Sep-89 | Sep-89 | Jun-89 | Jun-89 |
| Coal counts | 317 | 317 | 331 | 329 | 311 | 314 | 316 | 317 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | 1.3 | 0.3 | - | - | - | - | - | - |
| Texto-ulminite | 13.6 | 24.0 | 17.8 | 4.0 | 1.9 | 11.8 | 6.6 | 1.6 |
| Eu-ulminite | 9.8 | 18.9 | 20.5 | 1.2 | 0.3 | 6.7 | 3.2 | 2.8 |
| Telocollinite | 0.3 | 2.2 | 0.9 | - | - | 2.5 | - | - |
| Attrinite | 10.7 | 13.2 | 12.7 | - | 20.3 | - | - | 0.9 |
| Densinite | 32.8 | 18.3 | 19.0 | 13.4 | 2.9 | 15.9 | 36.4 | 15.5 |
| Desmocollinite | 7.6 | 6.3 | 10.6 | 64.7 | 0.3 | 51.9 | 35.1 | 66.2 |
| Corpogelinite | 8.2 | 4.1 | 2.4 | 3.6 | 2.3 | 2.9 | 5.1 | 4.1 |
| Porigelinite | 0.3 | - | 0.9 | - | - | - | 0.3 | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *84.5* | *87.4* | *84.9* | *86.9* | *28.0* | *91.7* | *86.7* | *91.2* |
| Sporinite | 0.6 | 0.3 | 1.5 | 0.9 | 7.1 | 1.3 | 2.5 | 0.9 |
| Cutinite | 1.6 | 0.9 | - | 4.6 | 0.6 | 2.9 | 1.3 | 3.2 |
| Resinite | 1.6 | 1.9 | 2.1 | 0.3 | 4.8 | - | 0.6 | 0.3 |
| Liptodetrinite | 7.3 | 6.3 | 6.6 | 3.6 | 42.1 | 2.5 | 6.0 | 3.5 |
| Alginite | 0.3 | 0.3 | - | 0.3 | 0.3 | - | 0.3 | 0.3 |
| Suberinite | 3.2 | 0.9 | 1.8 | 0.3 | 3.2 | 0.3 | 0.3 | - |
| Fluorinite | - | - | - | - | - | 1.0 | 0.3 | 0.3 |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 0.6 | 1.3 | 2.1 | - | 7.7 | - | 0.9 | - |
| *Total Liptinite* | *15.1* | *12.0* | *14.2* | *10.0* | *65.9* | *8.0* | *12.3* | *8.5* |
| Fusinite | - | - | 0.6 | 0.9 | 0.3 | 0.3 | 0.6 | - |
| Semifusinite | - | - | - | 0.3 | - | - | - | - |
| Funginite | - | - | - | 0.3 | 2.9 | - | - | - |
| Inertodetrinite | 0.3 | 0.3 | 0.3 | 0.3 | 2.9 | - | 0.3 | 0.3 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | 0.3 | - | 1.2 | - | - | - | - |
| *Total Inertinite* | *0.3* | *0.6* | *0.9* | *3.0* | *6.1* | *0.3* | *0.9* | *0.3* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | 0.6 | - | - | - | - | - | - |
| Massive telovitrinite | 12.9 | 34.7 | 30.8 | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 |
| **Maceral Indices** | | | | | | | | |
| VPI | 32.8 | 54.5 | 48.1 | 6.2 | 8.8 | 23.7 | 12.1 | 5.1 |
| MTI | 51.9 | 76.4 | 78.5 | 0.0 | 0.0 | 9.1 | 0.0 | 0.0 |
| LPI | 50.0 | 41.2 | 45.0 | 63.6 | 27.6 | 63.6 | 45.7 | 57.7 |
| GI-1 | 47.1 | 41.2 | 47.8 | 91.4 | 8.4 | 88.3 | 74.6 | 89.5 |
| GI-2 | 50.8 | 44.8 | 53.0 | 125.4 | 48.4 | 103.4 | 89.2 | 125.2 |
| LEI | 40.9 | 34.5 | 34.3 | 75.8 | 44.3 | 68.0 | 57.8 | 72.3 |
| LAI | 4.3 | 11.8 | 17.5 | 0.0 | 13.3 | 13.6 | 11.4 | 3.8 |

Appendix C2: Maceral data from point counts (sheet 11 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 |
| Depth | 63.05 | 63.40 | 63.8 | 64.30 | 64.40 | 64.80 | 65.30 | 65.70 |
| Seam | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 |
| Ply | B1-4 | B1-4 | B1-4 | B1-4 | B1-4 | B1-3 | B1-3 | B1-3 |
| Facies | Ia | Ia | Ib | Ib | IIa | IIa | IIa | IIa |
| **Examination** | | | | | | | | |
| Date | Sep-87 | Jun-89 | Sep-87 | Sep-87 | Sep-87 | Sep-87 | Jun-89 | Oct-87 |
| Coal counts | 315 | 347 | 342 | 331 | 342 | 377 | 313 | 339 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | 34.9 | - | - | - | - | - | 0.3 |
| Texto-ulminite | 33.0 | 61.7 | 20.5 | 10.0 | 23.1 | 15.4 | 31.6 | 18.9 |
| Eu-ulminite | 8.3 | 0.3 | 2.0 | 4.2 | 3.8 | 5.8 | 3.2 | 10.3 |
| Telocollinite | - | - | - | - | - | - | - | 0.6 |
| Attrinite | 2.2 | 0.3 | 33.9 | 17.5 | 11.1 | 40.6 | 10.2 | 11.8 |
| Densinite | 22.2 | 0.6 | 21.6 | 11.2 | 30.7 | 15.9 | 30.4 | 38.6 |
| Desmocollinite | 13.7 | 0.3 | 0.9 | - | 4.1 | - | 0.3 | 0.9 |
| Corpogelinite | 5.1 | - | 5.6 | 6.6 | 6.1 | 10.6 | 12.1 | 8.3 |
| Porigelinite | - | - | - | 0.3 | 0.3 | 1.6 | 1.6 | 0.3 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *84.4* | *98.0* | *84.5* | *49.8* | *79.2* | *89.9* | *89.5* | *90.0* |
| Sporinite | - | - | 0.9 | 0.9 | 1.2 | 0.3 | - | - |
| Cutinite | 0.6 | - | 0.3 | - | 0.3 | 0.3 | 0.6 | 0.3 |
| Resinite | 6.7 | 0.3 | 4.4 | 20.5 | 11.4 | 1.3 | 1.3 | 2.1 |
| Liptodetrinite | 3.8 | 1.4 | 3.5 | 15.7 | 3.5 | 5.3 | 2.6 | 3.5 |
| Alginite | 0.3 | - | - | - | - | - | - | - |
| Suberinite | 3.2 | - | 5.3 | 10.9 | 1.8 | 2.1 | 5.1 | 2.9 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 0.6 | - | 0.6 | 1.5 | 0.3 | - | 0.3 | - |
| *Total Liptinite* | *15.2* | *1.7* | *14.9* | *49.5* | *18.4* | *9.3* | *9.9* | *8.8* |
| Fusinite | - | - | - | - | 1.5 | 0.3 | - | 0.9 |
| Semifusinite | 0.3 | - | 0.3 | - | - | 0.3 | - | 0.3 |
| Funginite | - | 0.3 | 0.3 | 0.3 | - | 0.3 | 0.3 | - |
| Inertodetrinite | - | - | - | 0.3 | 0.6 | - | 0.3 | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | 0.3 | - | - | - |
| *Total Inertinite* | *0.3* | *0.3* | *0.6* | *0.6* | *2.3* | *0.8* | *0.6* | *1.2* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | 0.6 | - | - | - | - | 0.3 | - | - |
| Massive telovitrinite | 33.7 | 62.0 | 7.3 | 0.3 | 1.8 | 4.5 | 8.0 | 3.8 |
| **Maceral Indices** | | | | | | | | |
| VPI | 52.0 | 98.8 | 28.5 | 33.1 | 36.9 | 27.3 | 46.0 | 37.0 |
| MTI | 81.5 | 64.0 | 32.5 | 2.1 | 6.5 | 21.3 | 22.9 | 12.7 |
| LPI | 73.9 | 16.7 | 75.5 | 67.3 | 80.6 | 42.9 | 73.3 | 60.0 |
| GI-1 | 65.1 | 50.3 | 21.3 | 20.1 | 42.6 | 14.8 | 38.1 | 39.6 |
| GI-2 | 46.8 | 2.0 | 38.8 | 39.0 | 40.2 | 40.8 | 30.1 | 40.1 |
| LEI | 15.3 | 41.8 | 20.3 | 18.3 | 18.2 | 31.8 | 20.0 | 23.9 |
| LAI | 4.3 | 0.0 | 4.1 | 3.1 | 1.6 | 0.0 | 3.3 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 12 of 22)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 11 | 12 | 13 /L610 | 14 | 15/L611 | 16 | 17 | 18 |
| Depth | 66.15 | 66.50 | 67.00 | 67.40 | 68.00 | 68.50 | 69.00 | 69.45 |
| Seam | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 |
| Ply | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 |
| Facies | IIa | IIa | Ic | IIa | IIa | IIa | IIa | IIa |
| **Examination** | | | | | | | | |
| Date | Jun-89 | Oct-87 | Jul-89 | Oct-87 | Jul-89 | Oct-87 | Jun-89 | Oct-87 |
| Coal counts | 317 | 312 | 315 | 326 | 345 | 330 | 330 | 339 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | 0.3 | - |
| Texto-ulminite | 19.2 | 26.3 | 15.2 | 16.9 | 22.0 | 13.6 | 7.9 | 24.2 |
| Eu-ulminite | 1.6 | 12.8 | 0.6 | 3.7 | 2.0 | 6.4 | 1.2 | 4.7 |
| Telocollinite | - | 1.3 | - | 0.3 | - | 0.3 | - | - |
| Attrinite | 39.4 | 4.8 | 36.2 | 33.7 | 30.1 | 13.3 | 34.8 | 18.9 |
| Densinite | 13.2 | 35.9 | 7.6 | 29.8 | 20.6 | 43.6 | 37.0 | 30.4 |
| Desmocollinite | 1.3 | 6.7 | - | 1.2 | 2.0 | 2.7 | 0.3 | 2.1 |
| Corpogelinite | 10.1 | 3.2 | 7.3 | 6.4 | 8.4 | 11.8 | 6.1 | 7.7 |
| Porigelinite | - | - | 0.3 | - | - | - | - | 0.3 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *84.9* | *91.0* | *67.3* | *92.0* | *85.2* | *91.8* | *87.6* | *88.2* |
| Sporinite | 0.6 | 1.0 | 0.3 | 0.6 | 0.3 | 0.6 | 1.5 | - |
| Cutinite | 1.6 | - | 0.3 | 0.6 | 0.3 | - | 0.6 | 1.8 |
| Resinite | 1.6 | 1.9 | 4.4 | 1.8 | 1.4 | 3.0 | 0.6 | 1.2 |
| Liptodetrinite | 2.8 | 2.2 | 21.3 | 2.5 | 5.2 | 1.8 | 5.5 | 1.8 |
| Alginite | - | - | - | 0.3 | 0.3 | - | - | - |
| Suberinite | 7.9 | 3.2 | 0.3 | 1.2 | 6.4 | 2.4 | 2.7 | 1.8 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | 0.3 | 1.3 | - | 0.6 | - | 0.3 | 0.3 |
| *Total Liptinite* | *14.5* | *8.7* | *27.9* | *7.1* | *14.5* | *7.9* | *11.2* | *6.8* |
| Fusinite | 0.3 | - | 0.6 | - | - | - | - | 3.2 |
| Semifusinite | - | 0.3 | 1.3 | 0.3 | - | - | 0.3 | 1.2 |
| Funginite | - | - | 1.3 | 0.6 | 0.3 | 0.3 | 0.6 | 0.6 |
| Inertodetrinite | 0.3 | - | 1.6 | - | - | - | - | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | - | 0.3 | - |
| *Total Inertinite* | *0.6* | *0.3* | *4.8* | *0.9* | *0.3* | *0.3* | *1.2* | *5.0* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | 0.3 | - | 0.3 | - | - | - | - | 1.2 |
| Massive telovitrinite | 1.3 | 7.1 | 3.5 | 2.1 | 4.1 | 1.2 | 0.0 | 1.8 |
| **Maceral Indices** | | | | | | | | |
| VPI | 27.8 | 46.0 | 26.6 | 24.4 | 31.3 | 25.4 | 11.5 | 36.0 |
| MTI | 6.1 | 17.5 | 22.0 | 10.3 | 16.9 | 6.0 | 0.0 | 6.1 |
| LPI | 80.4 | 73.1 | 20.2 | 65.2 | 62.5 | 76.9 | 50.0 | 72.7 |
| GI-1 | 15.4 | 52.1 | 9.5 | 25.4 | 23.9 | 41.3 | 26.5 | 34.0 |
| GI-2 | 39.6 | 43.8 | 38.1 | 42.3 | 39.0 | 45.4 | 45.9 | 38.0 |
| LEI | 23.5 | 24.7 | 39.4 | 39.6 | 24.5 | 19.9 | 43.5 | 22.3 |
| LAI | 0.0 | 3.8 | 4.8 | 0.0 | 4.2 | 0.0 | 2.8 | 4.5 |

Appendix C2: Maceral data from point counts (sheet 13 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 19 /L612 | 20 | 22 | 23 | 24 | 25 | 26 | 27 |
| Depth | 70.10 | 70.45 | 71.00 | 71.40 | 72.00 | 72.40 | 72.90 | 73.60 |
| Seam | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 |
| Ply | B1-3 | B1-3 | B1-3 | B1-2 | B1-2 | B1-2 | B1-2 | B1-1 |
| Facies | IIa | IIa | IIa | Ia | Ia | Ia | Ia | Ia |
| **Examination** | | | | | | | | |
| Date | Jul-89 | Oct-87 | Jun-89 | Oct-87 | Oct-87 | Jun-89 | Oct-87 | Jun-89 |
| Coal counts | 308 | 353 | 309 | 343 | 326 | 318 | 337 | 312 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | 0.3 | - | - |
| Texto-ulminite | 17.9 | 17.0 | 36.6 | 13.4 | 13.2 | 20.8 | 16.0 | 17.6 |
| Eu-ulminite | 3.2 | 6.2 | 4.9 | 7.0 | 12.6 | 2.5 | 5.9 | 7.4 |
| Telocollinite | - | 0.3 | - | 0.3 | - | - | - | - |
| Attrinite | 15.6 | 11.0 | 4.2 | 12.0 | 11.3 | 23.9 | 43.9 | 19.6 |
| Densinite | 37.3 | 36.3 | 34.0 | 39.1 | 35.0 | 33.0 | 9.2 | 25.3 |
| Desmocollinite | 6.5 | 2.8 | 3.9 | 2.0 | 2.8 | 0.6 | 0.6 | 0.6 |
| Corpogelinite | 7.1 | 13.9 | 5.8 | 11.1 | 9.5 | 6.3 | 7.4 | 7.4 |
| Porigelinite | - | 0.3 | - | 0.3 | 0.3 | - | 0.3 | 1.0 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *87.7* | *87.8* | *89.3* | *85.1* | *84.7* | *87.4* | *83.4* | *78.8* |
| Sporinite | - | 0.3 | 0.3 | 0.3 | 1.5 | 0.6 | 1.2 | 1.0 |
| Cutinite | 0.6 | 0.6 | 1.6 | 0.3 | - | 0.3 | 0.6 | 1.3 |
| Resinite | 2.3 | 2.5 | 1.3 | 2.9 | 2.5 | 2.5 | 2.4 | 3.8 |
| Liptodetrinite | 3.6 | 3.1 | 3.9 | 3.2 | 4.0 | 5.0 | 5.3 | 6.7 |
| Alginite | - | - | - | 0.3 | - | - | - | - |
| Suberinite | 4.5 | 4.8 | 2.9 | 7.3 | 6.7 | 3.5 | 6.2 | 5.1 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | - | - | - | - | 0.3 | - | 0.3 |
| *Total Liptinite* | *11.0* | *11.3* | *10.0* | *14.3* | *14.7* | *12.3* | *15.7* | *18.3* |
| Fusinite | - | - | 0.6 | - | - | - | 0.3 | - |
| Semifusinite | 1.0 | 0.3 | - | 0.3 | - | 0.3 | 0.3 | 1.0 |
| Funginite | - | 0.3 | - | 0.3 | 0.3 | - | 0.3 | 0.6 |
| Inertodetrinite | 0.3 | 0.3 | - | - | 0.3 | - | - | 1.3 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | - | - | - |
| *Total Inertinite* | *1.3* | *0.8* | *0.6* | *0.6* | *0.6* | *0.3* | *0.9* | *2.9* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | 0.3 | 0.6 | 1.3 |
| Massive telovitrinite | 0.6 | 2.8 | 6.1 | 6.1 | 14.4 | 6.9 | 11.0 | 10.3 |
| **Maceral Indices** | | | | | | | | |
| VPI | 26.2 | 31.9 | 49.6 | 28.1 | 34.4 | 29.1 | 29.0 | 35.5 |
| MTI | 3.1 | 12.0 | 14.8 | 29.6 | 56.0 | 29.3 | 50.0 | 41.0 |
| LPI | 67.6 | 72.5 | 61.3 | 77.6 | 72.9 | 57.9 | 66.0 | 62.5 |
| GI-1 | 42.6 | 42.0 | 49.7 | 40.9 | 41.5 | 30.2 | 10.5 | 29.7 |
| GI-2 | 47.4 | 42.9 | 33.2 | 44.2 | 45.2 | 38.3 | 41.0 | 38.9 |
| LEI | 22.7 | 21.9 | 39.1 | 18.1 | 24.6 | 26.2 | 25.1 | 24.2 |
| LAI | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.6 | 0.0 | 1.8 |

Appendix C2: Maceral data from point counts (sheet 14 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 28 | 29/L613 | 30 | 31/L614 | 32 | 34 | 35/L615 | 36 |
| Depth | 74.20 | 74.50 | 74.80 | 75.50 | 75.55 | 77.20 | 77.50 | 78.20 |
| Seam | B1 | B1 | B1 | B1 | B1 | B3 | B3 | B3 |
| Ply | B1-1 | B1-1 | B1-1 | B1-1 | B1-1 | B3-7 | B3-7 | B3-7 |
| Facies | Ib | Ib | Ib | Ib | IIa | Ib | Ib | Ib |
| **Examination** | | | | | | | | |
| Date | Oct-87 | Jul-89 | Nov-87 | Jul-89 | Nov-87 | Nov-87 | Jul-89 | Nov-87 |
| Coal counts | 350 | 370 | 333 | 321 | 348 | 335 | 326 | 329 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | - |
| Texto-ulminite | 15.4 | 9.5 | 22.2 | 17.1 | 34.2 | 8.1 | 9.2 | 12.2 |
| Eu-ulminite | 2.6 | 1.6 | 3.3 | 2.2 | 6.9 | 3.6 | 3.1 | 4.0 |
| Telocollinite | 0.3 | - | 0.3 | - | 2.0 | - | - | - |
| Attrinite | 23.7 | 40.0 | 3.0 | 15.3 | 1.7 | 28.4 | 33.4 | 20.4 |
| Densinite | 36.6 | 13.8 | 47.4 | 41.4 | 28.2 | 21.2 | 31.6 | 32.8 |
| Desmocollinite | 1.1 | - | 9.9 | 1.9 | 8.6 | 0.3 | 0.9 | 1.8 |
| Corpogelinite | 9.7 | 10.8 | 3.3 | 10.0 | 14.4 | 10.4 | 9.2 | 10.3 |
| Porigelinite | 0.3 | 0.3 | 0.6 | 0.3 | 0.3 | - | - | 0.3 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *89.7* | *75.9* | *90.1* | *88.2* | *96.3* | *71.9* | *87.4* | *81.8* |
| Sporinite | 0.6 | 1.9 | 0.6 | 0.3 | 0.6 | 0.6 | 0.6 | 0.6 |
| Cutinite | 0.3 | 0.5 | - | - | - | 0.6 | 0.6 | - |
| Resinite | 2.6 | 2.4 | 2.1 | 3.1 | 0.6 | 7.8 | 1.2 | 4.6 |
| Liptodetrinite | 3.7 | 11.1 | 2.1 | 4.0 | 0.9 | 12.2 | 6.4 | 8.5 |
| Alginite | - | 0.3 | - | 0.3 | - | - | 0.3 | 0.3 |
| Suberinite | 2.0 | 1.9 | 2.7 | 1.2 | 0.9 | 5.7 | 1.5 | 3.3 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | 0.3 | - | - | - | - | - | - | - |
| Bituminite | 0.3 | 1.1 | - | 0.3 | - | - | - | - |
| *Total Liptinite* | *9.7* | *19.2* | *7.5* | *9.3* | *2.9* | *26.9* | *10.7* | *17.3* |
| Fusinite | 0.3 | - | 0.9 | 0.3 | - | - | - | 0.3 |
| Semifusinite | 0.3 | 2.2 | 0.6 | 0.6 | 0.3 | 0.6 | - | 0.3 |
| Funginite | - | 2.2 | 0.9 | 0.9 | 0.6 | 0.3 | 1.2 | 0.3 |
| Inertodetrinite | - | 0.5 | - | 0.6 | - | - | 0.6 | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | 0.3 | - | - |
| *Total Inertinite* | *0.6* | *4.9* | *2.4* | *2.5* | *0.9* | *1.2* | *1.8* | *0.9* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | 0.3 | - | - | - | 0.6 | 0.6 | - |
| Massive telovitrinite | 0.9 | 4.9 | 15.0 | 1.2 | 9.8 | 2.7 | 0.3 | 2.1 |
| **Maceral Indices** | | | | | | | | |
| VPI | 22.9 | 17.1 | 30.0 | 24.8 | 52.8 | 18.9 | 15.7 | 22.6 |
| MTI | 4.7 | 43.9 | 58.1 | 6.5 | 22.7 | 23.1 | 2.5 | 13.2 |
| LPI | 59.4 | 38.8 | 72.0 | 55.2 | 70.0 | 54.4 | 40.0 | 50.9 |
| GI-1 | 32.0 | 13.6 | 55.8 | 38.8 | 59.0 | 22.4 | 25.9 | 33.5 |
| GI-2 | 42.4 | 43.5 | 49.1 | 41.8 | 41.3 | 44.5 | 45.8 | 44.5 |
| LEI | 28.4 | 41.8 | 22.6 | 28.8 | 35.5 | 25.5 | 38.9 | 30.3 |
| LAI | 3.1 | 6.0 | 0.0 | 3.4 | 0.0 | 0.0 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 15 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 37 | 38 | 39 | 40 | 41/L616 | 42 | 43 | 44/L617 |
| Depth | 78.60 | 79.05 | 79.40 | 80.00 | 80.50 | 81.00 | 81.45 | 81.90 |
| Seam | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 |
| Ply | B3-7 | B3-6 | B3-6 | B3-5 | B3-4 | B3-4 | B3-4 | B3-3 |
| Facies | Ia | Ib | Ib | Ib | Ib | Ib | Ib | Ia |
| **Examination** | | | | | | | | |
| Date | Jun-89 | Nov-87 | Jun-89 | Nov-87 | Jul-89 | Nov-87 | Nov-87 | Jul-89 |
| Coal counts | 325 | 330 | 331 | 343 | 340 | 330 | 327 | 320 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | 0.3 |
| Texto-ulminite | 25.5 | 13.9 | 31.7 | 13.1 | 13.5 | 19.7 | 14.1 | 11.9 |
| Eu-ulminite | 3.1 | 6.7 | 3.3 | 5.5 | 2.4 | 4.8 | 6.4 | 3.1 |
| Telocollinite | - | - | - | 0.6 | - | 1.2 | 0.3 | - |
| Attrinite | 15.4 | 16.1 | 6.3 | 17.2 | 10.3 | 6.1 | 10.1 | 28.1 |
| Densinite | 30.5 | 37.9 | 39.6 | 41.4 | 44.7 | 45.2 | 36.1 | 26.3 |
| Desmocollinite | 0.9 | 1.5 | 0.9 | - | 0.6 | 2.4 | 0.6 | - |
| Corpogelinite | 8.3 | 10.3 | 7.9 | 6.1 | 7.4 | 7.9 | 10.7 | 5.3 |
| Porigelinite | 0.3 | - | - | - | 0.3 | 1.2 | 0.3 | 0.6 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *84.0* | *86.4* | *89.7* | *84.0* | *79.1* | *88.5* | *78.6* | *75.6* |
| Sporinite | 0.3 | - | - | 1.5 | 0.6 | 0.6 | 0.9 | - |
| Cutinite | 0.6 | - | 0.9 | - | - | - | 0.9 | 1.6 |
| Resinite | 4.9 | 3.6 | 1.8 | 3.8 | 4.4 | 3.6 | 6.7 | 4.4 |
| Liptodetrinite | 6.2 | 4.2 | 3.0 | 5.8 | 9.4 | 3.0 | 6.1 | 10.9 |
| Alginite | - | 0.3 | - | - | - | 0.3 | 0.3 | - |
| Suberinite | 3.7 | 4.8 | 3.3 | 2.9 | 4.7 | 3.0 | 5.2 | 5.6 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | 0.3 | 0.6 | 0.6 | - | 0.3 | 0.3 | 1.3 |
| *Total Liptinite* | *15.7* | *13.3* | *9.7* | *14.6* | *19.1* | *10.9* | *20.5* | *23.8* |
| Fusinite | - | - | 0.3 | - | 0.6 | - | - | - |
| Semifusinite | - | - | - | 0.3 | 0.3 | 0.3 | 0.9 | 0.3 |
| Funginite | 0.3 | 0.3 | 0.3 | 0.9 | 0.6 | 0.3 | - | - |
| Inertodetrinite | - | - | - | 0.3 | 0.3 | - | - | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | - | - | 0.3 |
| *Total Inertinite* | *0.3* | *0.3* | *0.6* | *1.5* | *1.8* | *0.6* | *0.9* | *0.6* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | - | 0.9 | 1.6 |
| Massive telovitrinite | 6.2 | 2.4 | 8.2 | 2.9 | 0.3 | 1.8 | 3.4 | 1.9 |
| **Maceral Indices** | | | | | | | | |
| VPI | 38.0 | 27.1 | 42.8 | 24.7 | 22.2 | 32.4 | 30.8 | 22.0 |
| MTI | 21.5 | 11.8 | 23.3 | 15.2 | 1.9 | 7.1 | 16.2 | 12.2 |
| LPI | 60.8 | 67.4 | 66.7 | 58.3 | 50.8 | 71.4 | 69.7 | 51.4 |
| GI-1 | 34.9 | 37.2 | 44.3 | 35.6 | 41.5 | 46.7 | 40.1 | 24.7 |
| GI-2 | 34.8 | 43.2 | 32.2 | 42.3 | 41.7 | 41.7 | 41.1 | 41.8 |
| LEI | 26.0 | 18.8 | 25.5 | 30.5 | 28.2 | 22.8 | 21.5 | 23.5 |
| LAI | 0.0 | 2.3 | 6.7 | 4.2 | 0.0 | 2.9 | 1.5 | 5.6 |

Appendix C2: Maceral data from point counts (sheet 16 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 45 | 46 | 47 | 48 | 49/L618 | 50 | 53 | 54 |
| Depth | 82.40 | 82.80 | 83.50 | 84.00 | 84.40 | 84.70 | 85.85 | 86.10 |
| Seam | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 |
| Ply | B3-3 | B3-3 | B3-3 | B3-3 | B3-2 | B3-2 | B3-1 | B3-1 |
| Facies | Ia | Ia | Ia | Ia | IIa | IIa | IIa | IIa |
| **Examination** | | | | | | | | |
| Date | Jun-89 | Nov-87 | Jun-89 | Nov-87 | Jul-89 | Nov-87 | Nov-87 | Nov-87 |
| Coal counts | 317 | 337 | 328 | 331 | 314 | 331 | 328 | 323 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | - | - | - |
| Texto-ulminite | 16.7 | 11.6 | 31.7 | 11.5 | 15.9 | 36.3 | 30.2 | 24.8 |
| Eu-ulminite | 10.1 | 8.0 | 12.8 | 10.9 | 13.4 | 14.8 | 19.2 | 9.9 |
| Telocollinite | - | - | - | 2.4 | 0.3 | 0.3 | 0.3 | - |
| Attrinite | 16.4 | 20.5 | 12.2 | 0.3 | 0.6 | 1.2 | 1.8 | 11.1 |
| Densinite | 29.0 | 32.0 | 24.7 | 23.3 | 23.9 | 15.7 | 30.2 | 18.9 |
| Desmocollinite | 2.5 | 2.1 | 0.9 | 36.3 | 15.6 | 13.6 | 10.4 | 11.5 |
| Corpogelinite | 4.7 | 8.0 | 5.2 | 3.3 | 6.7 | 6.6 | 4.9 | 1.9 |
| Porigelinite | 0.3 | 1.2 | - | - | 0.3 | 0.3 | - | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *79.8* | *83.4* | *87.5* | *87.9* | *76.8* | *88.8* | *97.0* | *78.0* |
| Sporinite | 0.3 | 1.2 | 1.2 | 1.2 | 0.3 | 0.3 | 0.3 | 1.5 |
| Cutinite | 0.6 | 0.6 | 0.6 | 0.3 | 2.2 | 0.9 | - | 5.3 |
| Resinite | 4.1 | 3.9 | 1.8 | 3.3 | 8.9 | 6.0 | - | 7.4 |
| Liptodetrinite | 7.9 | 5.6 | 5.8 | 4.2 | 1.9 | 0.3 | - | 2.5 |
| Alginite | - | 0.6 | - | - | - | - | - | - |
| Suberinite | 5.7 | 3.6 | 2.7 | 2.7 | 9.6 | 2.4 | 2.1 | 4.6 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | - | - | - | - | - | 0.3 | - | - |
| *Total Liptinite* | *18.6* | *15.4* | *12.2* | *11.8* | *22.9* | *10.3* | *2.4* | *21.4* |
| Fusinite | 0.3 | 0.3 | - | 0.3 | - | 0.6 | - | 0.3 |
| Semifusinite | 0.3 | 0.6 | 0.3 | - | - | 0.3 | 0.3 | - |
| Funginite | 0.6 | - | - | - | 0.3 | - | 0.3 | 0.3 |
| Inertodetrinite | 0.3 | - | - | - | - | - | - | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | 0.3 | - | - | - | - | - | - |
| *Total Inertinite* | *1.6* | *1.2* | *0.3* | *0.3* | *0.3* | *0.9* | *0.6* | *0.6* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | 0.3 | 0.3 | 0.6 | - | 1.6 | - | - | 1.9 |
| Massive telovitrinite | 15.1 | 9.2 | 31.4 | 13.6 | 5.4 | 5.1 | 7.0 | 5.9 |
| **Maceral Indices** | | | | | | | | |
| VPI | 35.9 | 26.4 | 54.1 | 29.3 | 42.5 | 62.7 | 54.0 | 45.5 |
| MTI | 56.5 | 47.0 | 70.5 | 54.9 | 18.3 | 10.0 | 14.1 | 17.0 |
| LPI | 57.6 | 63.5 | 52.5 | 64.1 | 91.7 | 97.0 | 100.0 | 88.4 |
| GI-1 | 35.9 | 33.5 | 35.4 | 80.1 | 68.7 | 70.3 | 60.1 | 50.6 |
| GI-2 | 42.6 | 45.4 | 32.4 | 87.6 | 61.4 | 45.1 | 45.4 | 49.3 |
| LEI | 25.1 | 32.2 | 34.2 | 31.3 | 9.2 | 14.1 | 13.4 | 29.6 |
| LAI | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 17 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B5 | B5 | B5 |
| Sample | 56 | 57 | 59 | 60 | 61 | 69.9 | 70.5 | 71 |
| Depth | 89.40 | 90.30 | 91.60 | 92.70 | 94.10 | 69.90 | 70.50 | 71.00 |
| Seam | C | C | C | C | C | B1 | B1 | B1 |
| Ply | C-? | C-? | C-? | C-? | C-? | B1-2 | B1-1 | B1-1 |
| Facies | Ib | Ib | Ib | Ib | Ib | Ia | Ib | Ib |
| **Examination** | | | | | | | | |
| Date | Nov-87 | Dec-87 | Jun-89 | Dec-87 | Dec-87 | Apr-87 | Jun-89 | May-87 |
| Coal counts | 317 | 330 | 338 | 328 | 323 | 676 | 311 | 568 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | - | - | - | - | - | 1.2 | - | 3.0 |
| Texto-ulminite | 24.0 | 13.3 | 19.8 | 8.2 | 11.1 | 15.8 | 11.9 | 24.5 |
| Eu-ulminite | 4.1 | 16.1 | 1.8 | 2.7 | 6.2 | 2.8 | 0.6 | 6.0 |
| Telocollinite | - | - | - | - | - | 0.3 | - | - |
| Attrinite | 27.4 | 37.0 | 29.3 | 43.6 | 35.3 | 26.2 | 27.0 | 13.6 |
| Densinite | 29.3 | 13.6 | 34.9 | 28.0 | 20.4 | 17.6 | 26.7 | 25.9 |
| Desmocollinite | - | 0.3 | - | - | - | - | 1.0 | 4.2 |
| Corpogelinite | 8.8 | 3.9 | 6.8 | 6.7 | 10.8 | 4.7 | 9.6 | 11.6 |
| Porigelinite | - | - | 0.3 | - | - | 0.9 | 0.6 | 0.4 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *93.7* | *84.2* | *92.9* | *89.3* | *83.9* | *69.5* | *77.5* | *89.1* |
| Sporinite | - | 0.9 | 0.6 | 0.9 | 0.9 | 0.7 | 0.3 | 0.5 |
| Cutinite | 0.3 | - | 1.2 | 0.6 | 1.2 | 0.6 | 0.6 | 0.9 |
| Resinite | 1.9 | 4.8 | 0.3 | 2.4 | 2.2 | 4.7 | 7.7 | 1.1 |
| Liptodetrinite | 2.2 | 5.8 | 3.0 | 4.6 | 6.5 | 14.1 | 8.4 | 3.9 |
| Alginite | - | 0.6 | - | - | 0.6 | 0.1 | - | 0.4 |
| Suberinite | 1.3 | 1.2 | 1.2 | 0.9 | 2.8 | 8.6 | 4.2 | 1.1 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | 0.3 | - | - | - | - |
| Bituminite | - | 0.6 | 0.3 | - | - | 0.1 | - | - |
| *Total Liptinite* | *5.7* | *13.9* | *6.5* | *9.8* | *14.2* | *29.0* | *21.2* | *7.7* |
| Fusinite | - | - | - | - | 0.3 | 0.4 | - | 0.2 |
| Semifusinite | - | 0.6 | 0.3 | 0.3 | 0.3 | 0.1 | 1.0 | 1.1 |
| Funginite | 0.3 | 1.2 | - | 0.6 | 1.2 | 0.3 | 0.3 | 0.2 |
| Inertodetrinite | 0.3 | - | 0.3 | - | - | 0.4 | - | 0.9 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | - | - | - | 0.1 | - | 0.9 |
| *Total Inertinite* | *0.6* | *1.8* | *0.6* | *0.9* | *1.9* | *1.5* | *1.3* | *3.2* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | 0.3 | - | - | 0.6 | 1.2 | - | 0.3 | - |
| Massive telovitrinite | 12.3 | 18.8 | 1.5 | 1.5 | 5.9 | 2.7 | 0.3 | 5.3 |
| **Maceral Indices** | | | | | | | | |
| VPI | 33.1 | 36.6 | 25.2 | 13.3 | 23.7 | 31.5 | 18.7 | 43.4 |
| MTI | 43.8 | 63.9 | 6.8 | 13.9 | 33.9 | 13.2 | 2.6 | 15.8 |
| LPI | 61.1 | 56.8 | 52.4 | 51.6 | 54.3 | 51.3 | 60.6 | 50.0 |
| GI-1 | 26.3 | 14.7 | 27.6 | 20.2 | 19.0 | 20.7 | 26.7 | 39.6 |
| GI-2 | 36.5 | 42.7 | 39.0 | 45.6 | 43.0 | 37.6 | 43.2 | 38.2 |
| LEI | 20.1 | 32.0 | 50.2 | 33.2 | 34.1 | 29.8 | 23.3 | 48.0 |
| LAI | 0.0 | 4.5 | 4.8 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 18 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 |
| Sample | 71.7 | 72.1 | 72.7 | 73.5 | 73.9 | 74.3 | 74.9 | 75.4 |
| Depth | 71.70 | 72.10 | 72.70 | 73.50 | 73.90 | 74.30 | 74.90 | 75.40 |
| Seam | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 |
| Ply | B3-7 | B3-7 | B3-7 | B3-6 | B3-6 | B3-6 | B3-5 | B3-5 |
| Facies | Ib | Ib | Ib | Ib | Ib | Ia | Ia | Ib |
| **Examination** | | | | | | | | |
| Date | May-87 | Jun-89 | May-87 | Jun-89 | Jun-87 | Sep-87 | Jun-89 | Aug-87 |
| Coal counts | 554 | 318 | 586 | 310 | 567 | 277 | 334 | 368 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | 0.5 | 0.3 | 2.6 | - | - | - | - | - |
| Texto-ulminite | 14.3 | 73.9 | 14.2 | 13.9 | 12.0 | 9.0 | 8.4 | 9.8 |
| Eu-ulminite | 6.7 | 24.5 | 2.0 | 2.9 | 3.7 | 8.7 | 7.2 | 1.6 |
| Telocollinite | 0.2 | - | 0.2 | - | - | 0.4 | - | - |
| Attrinite | 23.8 | - | 19.3 | 6.8 | 24.0 | 28.5 | 15.9 | 25.8 |
| Densinite | 30.0 | - | 31.4 | 46.1 | 34.7 | 26.7 | 35.3 | 35.1 |
| Desmocollinite | 3.1 | 0.6 | 2.6 | 10.0 | 4.2 | 1.1 | 4.8 | 2.7 |
| Corpogelinite | 7.0 | - | 6.3 | 9.0 | 7.8 | 9.0 | 12.0 | 11.4 |
| Porigelinite | 0.4 | - | 0.3 | 0.3 | 0.2 | - | - | - |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *85.9* | *99.4* | *78.8* | *89.0* | *86.6* | *83.4* | *83.5* | *86.4* |
| Sporinite | 0.5 | - | 1.5 | 0.6 | 0.7 | 0.7 | 1.2 | 0.3 |
| Cutinite | 0.9 | - | 1.0 | - | 0.4 | 0.7 | 0.6 | - |
| Resinite | 2.5 | 0.6 | 3.6 | 2.9 | 1.9 | 4.3 | 3.0 | 1.6 |
| Liptodetrinite | 6.0 | - | 7.7 | 4.8 | 6.0 | 6.1 | 7.2 | 8.7 |
| Alginite | 0.2 | - | 0.9 | - | - | - | - | - |
| Suberinite | 2.2 | - | 3.8 | 1.6 | 2.6 | 3.6 | 2.7 | 2.2 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | 0.3 |
| Bituminite | 0.2 | - | 0.5 | - | 0.2 | - | 0.6 | - |
| *Total Liptinite* | *12.5* | *0.6* | *18.9* | *10.0* | *11.8* | *15.5* | *15.3* | *13.0* |
| Fusinite | - | - | 0.3 | - | - | - | - | - |
| Semifusinite | 0.4 | - | 0.5 | 0.6 | 0.2 | - | 0.6 | 0.3 |
| Funginite | 0.7 | - | 1.0 | - | 0.5 | 0.4 | 0.6 | 0.3 |
| Inertodetrinite | 0.5 | - | 0.2 | 0.3 | 0.7 | 0.4 | - | - |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | - | - | 0.2 | - | 0.2 | 0.4 | - | - |
| *Total Inertinite* | *1.6* | *0.0* | *2.2* | *1.0* | *1.6* | *1.1* | *1.2* | *0.5* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | - | - | - | - | 0.7 | - | - |
| Massive telovitrinite | 8.8 | 98.4 | 5.1 | 6.1 | 1.8 | 6.5 | 4.8 | 0.8 |
| **Maceral Indices** | | | | | | | | |
| VPI | 27.6 | 99.4 | 26.2 | 21.1 | 20.0 | 24.3 | 21.8 | 15.2 |
| MTI | 40.8 | 99.7 | 27.0 | 36.5 | 11.2 | 36.0 | 30.8 | 7.1 |
| LPI | 51.5 | 100.0 | 58.3 | 51.6 | 48.5 | 60.5 | 51.0 | 31.9 |
| GI-1 | 32.2 | 100.0 | 34.7 | 52.7 | 34.7 | 26.1 | 40.4 | 32.2 |
| GI-2 | 45.1 | 14.0 | 42.6 | 54.1 | 48.2 | 46.1 | 51.2 | 47.6 |
| LEI | 37.3 | 1.0 | 38.7 | 31.1 | 34.7 | 25.0 | 35.7 | 35.7 |
| LAI | 1.5 | 0.0 | 2.8 | 0.0 | 1.5 | 0.0 | 4.1 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 19 of 21)

| **Sample Details** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hole | B5 | B5 | B5 | B5 | B5 | B5 | B5 |
| Sample | 75.9/L600 | 76.4 | 76.9/L601 | 77.6 | 78.1/L602 | 78.65 | 80.95 |
| Depth | 75.90 | 76.40 | 76.90 | 77.60 | 78.10 | 78.65 | 80.95 |
| Seam | B3 | B3 | B3 | B3 | B3 | B3 | C |
| Ply | B3-4 | B3-4 | B3-3 | B3-3 | B3-3 | B1-2 | C-5 |
| Facies | Ib | Ib | Ib | Ia | Ib | IIa | Ia |
| **Examination** | | | | | | | |
| Date | Jul-89 | Jun-87 | Jun-89 | Au-87 | Jun-89 | Ap-87 | Jun-89 |
| Coal counts | 312 | 577 | 319 | 370 | 320 | 567 | 321 |
| **Macerals (% mmf)** | | | | | | | |
| Textinite | - | - | - | - | - | 0.9 | - |
| Texto-ulminite | 18.3 | 5.9 | 21.3 | 28.6 | 14.4 | 18.0 | 12.8 |
| Eu-ulminite | 1.9 | 2.1 | 6.3 | 13.0 | 5.3 | 8.3 | 1.2 |
| Telocollinite | - | 0.2 | - | - | - | - | - |
| Attrinite | 35.9 | 26.7 | 2.2 | 4.9 | 6.6 | 6.3 | 41.7 |
| Densinite | 26.3 | 33.6 | 37.0 | 25.4 | 36.9 | 30.7 | 22.4 |
| Desmocollinite | 1.6 | 2.4 | 17.9 | 7.8 | 9.4 | 11.5 | 0.3 |
| Corpogelinite | 8.0 | 10.1 | 3.4 | 4.9 | 9.7 | 3.9 | 8.1 |
| Porigelinite | - | 0.5 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 |
| Eugelinite | - | - | - | - | - | - | - |
| *Total Vitrinite* | *92.0* | *81.5* | *88.4* | *84.9* | *82.5* | *79.7* | *86.9* |
| Sporinite | - | 0.5 | 0.3 | 0.5 | 1.3 | 0.5 | 0.6 |
| Cutinite | 0.3 | 0.5 | - | 1.4 | 0.6 | - | 0.6 |
| Resinite | 0.6 | 4.2 | 2.5 | 4.9 | 5.0 | 4.6 | 1.6 |
| Liptodetrinite | 3.5 | 7.6 | 4.7 | 5.4 | 6.3 | 4.6 | 7.2 |
| Alginite | - | 0.2 | - | - | - | - | - |
| Suberinite | 2.2 | 3.8 | 2.5 | 1.9 | 3.1 | 8.8 | 2.5 |
| Fluorinite | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - |
| Bituminite | - | - | - | - | - | - | - |
| *Total Liptinite* | *6.7* | *16.8* | *10.0* | *14.1* | *16.3* | *18.5* | *12.5* |
| Fusinite | - | 0.3 | 0.6 | - | - | 0.5 | 0.6 |
| Semifusinite | 0.6 | 0.2 | 0.6 | 0.3 | - | 0.9 | - |
| Funginite | 0.6 | 0.2 | 0.3 | 0.8 | 0.6 | 0.2 | - |
| Inertodetrinite | - | 0.5 | - | - | 0.3 | 0.2 | - |
| Micrinite | - | - | - | - | - | - | - |
| Macrinite | - | 0.5 | - | - | 0.3 | - | - |
| *Total Inertinite* | *1.3* | *1.7* | *1.6* | *1.1* | *1.3* | *1.8* | *0.6* |
| **Sub-macerals *** | | | | | | | |
| Cutinite "L" | 0.3 | 0.5 | - | 0.8 | 0.6 | - | - |
| Massive telovitrinite | 1.6 | 0.9 | 16.9 | 36.5 | 2.8 | 6.5 | 8.7 |
| **Maceral Indices** | | | | | | | |
| VPI | 24.0 | 11.5 | 32.6 | 52.2 | 27.2 | 35.9 | 17.9 |
| MTI | 7.9 | 10.6 | 61.4 | 87.7 | 14.3 | 24.0 | 62.2 |
| LPI | 47.6 | 54.6 | 53.1 | 61.5 | 61.5 | 75.2 | 42.5 |
| GI-1 | 23.7 | 31.1 | 63.8 | 54.0 | 52.8 | 55.4 | 18.5 |
| GI-2 | 41.7 | 49.8 | 58.8 | 42.3 | 53.3 | 53.0 | 43.0 |
| LEI | 26.7 | 27.3 | 27.1 | 27.5 | 27.5 | 16.0 | 39.1 |
| LAI | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 20 of 21)

| **Sample Details** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hole | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 |
| Sample | 81.5 | 82.5 | 83.55 | 84 | 84.5 | 84.95 | 85.5 | 85.95 |
| Depth | 81.50 | 82.50 | 83.55 | 84.00 | 84.50 | 84.95 | 85.50 | 85.95 |
| Seam | C | C | C | C | C | C | C | C |
| Ply | C-5 | C-5 | C-5 | C-5 | C-5 | C-5 | C-4 | C-4 |
| Facies | Ia | Ib | Ib | Ib | Ib | Ib | Ia | Ia |
| **Examination** | | | | | | | | |
| Date | Ap-87 | Aug-87 | May-87 | Jun-89 | Aug-87 | Jun-89 | Sep-87 | Apr-87 |
| Coal counts | 652 | 448 | 558 | 328 | 332 | 329 | 328 | 576 |
| **Macerals (% mmf)** | | | | | | | | |
| Textinite | 0.3 | - | 0.9 | - | - | - | - | 0.5 |
| Texto-ulminite | 21.2 | 10.9 | 17.7 | 16.5 | 8.4 | 12.2 | 92.7 | 37.2 |
| Eu-ulminite | 4.1 | 9.2 | 4.8 | 1.5 | 3.9 | 1.8 | 7.0 | 7.5 |
| Telocollinite | 0.2 | - | - | - | - | - | - | 0.2 |
| Attrinite | 34.4 | 41.1 | 33.0 | 43.6 | 39.8 | 46.2 | - | 27.3 |
| Densinite | 9.2 | 16.7 | 18.8 | 18.6 | 24.4 | 18.8 | - | 7.5 |
| Desmocollinite | 0.8 | 0.4 | 0.5 | 1.2 | 0.6 | - | - | 1.0 |
| Corpogelinite | 6.1 | 9.2 | 7.9 | 5.8 | 11.4 | 4.3 | - | 2.4 |
| Porigelinite | 0.5 | - | - | 0.3 | 0.3 | 0.3 | - | 0.3 |
| Eugelinite | - | - | - | - | - | - | - | - |
| *Total Vitrinite* | *76.7* | *87.5* | *83.7* | *87.5* | *88.9* | *83.6* | *99.7* | *83.9* |
| Sporinite | 0.6 | 0.2 | 0.7 | 0.3 | 0.3 | 1.2 | - | 0.3 |
| Cutinite | 0.8 | 0.4 | 0.5 | 0.3 | 0.3 | 0.6 | - | 0.9 |
| Resinite | 6.9 | 2.2 | 3.2 | 3.0 | 1.5 | 2.7 | 0.3 | 2.8 |
| Liptodetrinite | 7.7 | 5.1 | 6.1 | 6.4 | 5.4 | 6.7 | - | 6.4 |
| Alginite | 0.5 | - | - | - | - | - | - | 0.5 |
| Suberinite | 2.6 | 2.0 | 4.3 | 0.9 | 2.4 | 4.6 | - | 2.1 |
| Fluorinite | - | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - | - |
| Bituminite | 0.3 | 0.4 | 0.2 | 0.3 | 0.3 | - | - | - |
| *Total Liptinite* | *19.3* | *10.5* | *15.1* | *11.3* | *10.2* | *15.8* | *0.3* | *13.0* |
| Fusinite | 0.6 | 0.2 | - | 0.3 | - | - | - | 0.2 |
| Semifusinite | 0.9 | 0.9 | 0.9 | 0.6 | 0.3 | 0.3 | - | 1.0 |
| Funginite | 1.1 | 0.9 | - | 0.3 | - | - | - | - |
| Inertodetrinite | 1.2 | - | 0.4 | - | 0.6 | 0.3 | - | 1.6 |
| Micrinite | - | - | - | - | - | - | - | - |
| Macrinite | 0.2 | - | - | - | - | - | - | 0.3 |
| *Total Inertinite* | *4.0* | *2.0* | *1.3* | *1.2* | *0.9* | *0.6* | *0.0* | *3.1* |
| **Sub-macerals *** | | | | | | | | |
| Cutinite "L" | - | 0.2 | 0.2 | - | 0.3 | - | - | 0.5 |
| Massive telovitrinite | 14.4 | 1.8 | 0.5 | 2.7 | 0.6 | 2.4 | 99.7 | 31.1 |
| **Maceral Indices** | | | | | | | | |
| VPI | 36.8 | 25.6 | 31.0 | 22.1 | 16.0 | 17.7 | 100.0 | 55.9 |
| MTI | 56.0 | 8.9 | 2.3 | 15.3 | 4.9 | 17.4 | 100.0 | 68.6 |
| LPI | 59.7 | 48.9 | 59.0 | 41.7 | 45.5 | 57.7 | 100.0 | 50.7 |
| GI-1 | 12.9 | 15.8 | 19.6 | 17.3 | 20.4 | 15.2 | - | 14.1 |
| GI-2 | 36.7 | 44.3 | 39.1 | 42.1 | 45.9 | 43.0 | 4.4 | 29.0 |
| LEI | 29.9 | 29.1 | 27.9 | 34.1 | 29.8 | 33.2 | 1.0 | 34.4 |
| LAI | 1.6 | 4.4 | 1.2 | 2.8 | 3.0 | 0.0 | 0.0 | 0.0 |

Appendix C2: Maceral data from point counts (sheet 21 of 21)

| **Sample Details** | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hole | B5 | B5 | B5 | B5 | B5 | B5 | B5 |
| Sample | 86.5 | 86.95 | 88 | 88.5/L604 | 89 | 90 | 91 |
| Depth | 86.50 | 86.95 | 88.00 | 88.50 | 89.00 | 90.00 | 91.00 |
| Seam | C | C | C | C | C | C | C |
| Ply | C-3 | C-3 | C-3 | C-3 | C-3 | C-2 | C-1 |
| Facies | Ib | Ib | Ib | Ib | Ib | Ia | II |
| **Examination** | | | | | | | |
| Date | Jun-89 | May-87 | Sep-87 | Jun-89 | Jun-87 | Aug-87 | Dec-87 |
| Coal counts | 331 | 601 | 304 | 321 | 610 | 363 | 316 |
| **Macerals (% mmf))** | | | | | | | |
| Textinite | - | 0.3 | - | - | - | - | - |
| Texto-ulminite | 15.7 | 13.6 | 12.2 | 9.3 | 10.0 | 17.9 | 6.3 |
| Eu-ulminite | 1.5 | - | 2.3 | 0.9 | 6.1 | 7.2 | 15.8 |
| Telocollinite | - | - | - | - | - | - | 0.9 |
| Attrinite | 45.6 | 39.4 | 43.1 | 44.2 | 43.1 | 29.5 | 1.9 |
| Densinite | 19.3 | 16.6 | 13.8 | 16.2 | 13.4 | 23.7 | 25.6 |
| Desmocollinite | 1.2 | - | - | 0.3 | 0.5 | - | 34.2 |
| Corpogelinite | 5.1 | 3.8 | 11.2 | 5.6 | 6.1 | 7.4 | 3.5 |
| Porigelinite | 0.3 | - | - | - | - | 0.3 | - |
| Eugelinite | - | - | - | - | - | - | - |
| *Total Vitrinite* | *88.8* | *73.9* | *82.6* | *76.6* | *79.2* | *86.0* | *88.3* |
| Sporinite | 0.6 | 1.5 | 0.7 | 0.3 | 1.1 | 0.3 | 0.6 |
| Cutinite | 0.6 | 0.8 | 2.0 | 0.9 | 0.7 | 1.7 | 0.9 |
| Resinite | 1.8 | 4.7 | 3.0 | 3.1 | 5.9 | 4.4 | 2.5 |
| Liptodetrinite | 5.4 | 11.1 | 7.2 | 14.0 | 8.2 | 6.1 | 5.1 |
| Alginite | - | 0.3 | 0.7 | - | 0.5 | - | 0.6 |
| Suberinite | 1.8 | 5.0 | 3.3 | 1.2 | 2.5 | 0.8 | 0.3 |
| Fluorinite | - | - | - | - | - | - | - |
| Exsudatinite | - | - | - | - | - | - | - |
| Bituminite | 0.3 | 0.3 | - | 2.5 | 0.2 | - | - |
| *Total Liptinite* | *10.6* | *23.8* | *16.8* | *22.1* | *19.0* | *13.2* | *10.1* |
| Fusinite | - | - | - | 0.3 | 0.2 | - | - |
| Semifusinite | 0.3 | 0.8 | 0.3 | 0.6 | 0.7 | - | 0.3 |
| Funginite | 0.3 | 0.2 | - | - | 0.5 | 0.3 | 0.9 |
| Inertodetrinite | - | 0.8 | 0.3 | 0.3 | 0.5 | 0.3 | 0.3 |
| Micrinite | - | - | - | - | - | - | - |
| Macrinite | - | 0.5 | - | - | - | 0.3 | - |
| *Total Inertinite* | *0.6* | *2.3* | *0.7* | *1.2* | *1.8* | *0.8* | *1.6* |
| **Sub-macerals *** | | | | | | | |
| Cutinite "L" | 0.3 | 0.5 | 0.7 | 0.6 | 0.3 | 1.7 | 0.3 |
| Massive telovitrinite | 2.1 | 0.5 | 1.6 | 0.3 | 3.8 | 14.9 | 18.0 |
| **Maceral Indices** | | | | | | | |
| VPI | 20.7 | 20.0 | 20.3 | 14.5 | 22.0 | 32.0 | 27.2 |
| MTI | 12.3 | 3.6 | 11.4 | 3.0 | 23.5 | 59.3 | 78.1 |
| LPI | 47.1 | 52.5 | 56.9 | 28.6 | 56.5 | 54.2 | 50.0 |
| GI-1 | 17.1 | 15.5 | 12.9 | 14.6 | 13.4 | 22.8 | 76.2 |
| GI-2 | 42.8 | 40.8 | 42.2 | 44.6 | 44.6 | 39.2 | 87.2 |
| LEI | 34.7 | 32.9 | 37.7 | 34.7 | 32.4 | 25.5 | 44.1 |
| LAI | 2.9 | 1.4 | 0.0 | 12.7 | 0.9 | 0.0 | 0.0 |

Key to Appendix C2:

- \- indicates maceral was not detected.
- * sub-macerals are locally defined and reflect variations in maceral characteristics and/or morphology (see Sections 3.4.2 and 5.3.6; Appendix C1). Only those sub-maceral used for maceral index derivation are included in this Appendix.

mmf denotes mineral matter free basis.

Maceral indices: VPI = Vitrinite preservation index, MTI = Massive telovitrinite index, LPI = Liptinite preservation index, GI = Gelification index, LEI = Liptinite environmental index and LAI = Liptinite alteration index (see Section 5.3).

A second facies variety shown in brackets indicates the sample shows some mixed characteristics.

Maceral analysis undertaken in accordance with AS 2856,2-1998.

# APPENDIX D
# BIOMARKER EVALUATION

Data pertaining to biomarker evaluation portion of the project is presented within this Appendix.

**APPENDIX D1: Compound characteristics and identification**

Summarises the aliphatic biomarkers detected in a series of class specific tabulations.

**APPENDIX D2: Representative mass spectra of major compounds**

Presents representative mass spectra for each of the major biomarkers.

**APPENDIX D3: RCI methodology and GC-MS peak measurements and RCI values**

Presents the methodology for RCI derivation (Appendix D3.1) and GC-MS peak data/RCI values for each of the named and correlated compounds (Appendix D3.2 to D3.9).

# APPENDIX D1
# COMPOUND CHARACTERISTICS AND IDENTIFICATION

The aliphatic biomarker suite encountered in Lochiel and Bowmans coals is presented in this appendix in a series of compound-class-specific tables (i.e. Tables D1.1 to D1.15, as elaborated in Chapter 8). The basis for compound assignment is also briefly outlined.

## D1.1 Saturated sesquiterpanes

Table D1.1 Possible saturated sesquiterpenoid compound suite (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| S10 | $C_{14}$ sesquiterpane | $C_{14}H_{26}$ | 194 | 165 | uncommon # | mod. - high |
| S21 | $C_{16}$ sesquiterpane | $C_{16}H_{30}$ | 222 | 81 | v. rare † | mod. - high |
| S25 | cadinane | $C_{15}H_{28}$ | 208 | 109/165 | common | moderate |
| S33 | $C_{15}$ sesquiterpane | $C_{15}H_{28}$ | 208 | 95 | rare # | low |
| S35 | santalane (?) | $C_{15}H_{28}$ | 208 | 123 | common | high |
| S36 | $C_{15}$ sesquiterpane | $C_{15}H_{28}$ | 208 | 95 | uncommon | low |
| S36.5 | $C_{15}$ sesquiterpane | $C_{15}H_{28}$ | 208 | 187 | v. rare # | low |
| S43 | similarities to 8β(H)-drimane | $C_{15}H_{28}$ | 208 | 124 | v. rare # | low |
| S45 | $C_{15}$ sesquiterpane | $C_{15}H_{28}$ | 208 | 137 | uncommon # | mod |
| S54 | similarities to eremophilane | $C_{15}H_{28}$ | 208 | 208 | rare | low |
| S57 | 8β(H)-drimane (?) | $C_{15}H_{28}$ | 208 | 123 | v. rare # | low |
| S67 | $C_{15}$ sesquiterpane | $C_{15}H_{28}$ | 208 | 95 | v. rare | moderate |
| S70a | similarities to bergamotane | $C_{15}H_{28}$ | 208 | 69 | v. rare † | moderate |
| S72 | $C_{15}$ sesquiterpane (?) | $C_{15}H_{28}$ | 208 | 71 | v. rare † | low |

Key: # Indicates detected in the Bowmans Deposit only
† Indicates detected in the Lochiel Deposit only
(?) Indicates tentative assignment
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

S25 was identified as cadinane by correlation to published mass spectra (van Aarssen *et al.*, 1992; Figure 2.6). Less confident assignments include santalane for S35, an unnamed $C_{15}$ bicyclic sesquiterpane for S67 and 8β(H)-drimane for S57, using published mass spectra of Moshonas and Lund (1970), Bendoraitis (1974) and Philp (1985), respectively. Spectral similarities were noted to a further three compounds, although these assignments are very provisional because of their low abundance and relatively weak spectra. These include S43 to 8β(H)-drimane (Philp, 1985), and S54 and S70 to eremophilane and beramotane (Moshonas and Lund, 1970).

## D1.2 Mono-unsaturated sesquiterpenes

Table D1.2 Possible mono-unsaturated sesquiterpene compound suite (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| S9 | $C_{14}$ sesquiterpene | $C_{14}H_{24}$ | 192 | 109 | v. rare # | low |
| S10.5 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 191 | uncommon | low - moderate |
| S14 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 135 | uncommon | low - moderate |
| S15 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 121? | uncommon | low - moderate |
| S20 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 191 | v. common | moderate - high |
| S32 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 163 | v. rare # | low |
| S34 | $C_{16}$ sesquiterpene | $C_{16}H_{28}$ | 220 | 177 | rare † | high |
| S34.5 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 177 | rare | low |
| S37 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 95 | v. rare † | moderate |
| S40 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 191 | v. common | high |
| S40.5 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 95 | uncommon | low - high |
| S40.7 | $C_{16}$ sesquiterpene | $C_{16}H_{28}$ | 220 | 163 | rare † | low |
| S41.5 | $C_{17}$ sesquiterpene | $C_{17}H_{30}$ | 234 | 219 | v. rare # | low |
| S43.5 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 177/191 | v. rare † | moderate |
| S44 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 191 | v. rare | moderate |
| S47 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 95 | v. rare | moderate |
| S50 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 81/191 | v. rare | low - moderate |
| S55 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 191 | uncommon | high |
| S60 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 81/206 | v. common | low - high |
| S66 | $C_{15}$ sesquiterpene | $C_{15}H_{26}$ | 206 | 81/206 | common | low - moderate |

Key: # Indicates detected in the Bowmans Deposit only
† Indicates detected in the Lochiel Deposit only
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Although strong mass spectra are available for a number of these compounds, no definitive identifications have been made. However, similar unidentified mass spectra showing a base peak at *m/z* 191 and molecular ion of $M^+$ 206 have been reported by Wang and Simoneit (1990) for unidentified hydrocarbons in brown coals. Compounds such as S10.5, S20, S40, S44 and S55 exhibit these features.

## D1.3 Di-unsaturated sesquiterpenoids

Table D1.3 Possible di-unsaturated sesquiterpenoid compound suite (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| S11 | sesquiterp-diene | $C_{15}H_{24}$ | 204 | 189 | uncommon | low – mod. |
| S13 | sesquiterp-diene | $C_{15}H_{24}$ | 204 | 161 | v. common | high |
| S13.5 | sesquiterp-diene, possibly Hostettler *et al.* (1989) "4" | $C_{15}H_{24}$ | 204 | 137 | uncommon # | low |
| S14.5 | sesquiterp-diene | $C_{15}H_{24}$ | 204 | 135 | rare # | low |
| S31 | curcumene (?) heptylxylene (?) α-cedrene(?) | $C_{15}H_{24}$ | 204 | 119 | common | moderate |
| S39.8 | sesquiterp-diene | $C_{15}H_{24}$ | 204 | 105/106 | common | mod. - high |
| S52 | sesquiterp-diene, possibly Hostettler *et al.* (1989) "5" | $C_{15}H_{24}$ | 204 | 161 | rare # | low – mod. |
| S58 | sesquiterp-diene (?) | $C_{15}H_{24}$ | ?204 | 109 | v. rare # | low |
| S70b | $C_{16}$ sesquiterp-diene (?) | $C_{16}H_{26}$ | ?218 | 85 | v. rare # | low |
| S73 | $C_{16}$ sesquiterp-diene | $C_{16}H_{26}$ | 218 | 203 | v. rare # | low – mod. |

Key: # Indicates detected in the Bowmans Deposit only
(?) Indicates tentative assignment
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

No members of the di-unsaturated suite have been positively identified. However, two compounds show a reasonable match with mass spectra published from surface sediments (Hostettler *et al.*, 1989). In particular, S13.5 and S52 are similar to their compounds "4" and "5", respectively. Neither was unambiguously identified by Hostettler *et al.* (1989), although the possibility of cadinene-type compounds was suggested. The compound designated S31 may be curcumene or α-cedrene, or alternatively heptylxylene, based on mass spectral data from Wang and Simoneit (1990).

## D1.4 Partially aromatised sesquiterpenoids

Table D1.4 Possible partially aromatised sesquiterpenoid compounds (in elution order)

| Identi-fier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| S56 | cuparene | $C_{15}H_{22}$ | 202 | 132 | v. rare | low - high |
| S59 | calamenene | $C_{15}H_{22}$ | 202 | 159 | common | high |
| S75 | 5,6,7,8-tetrahydrocadalene | $C_{15}H_{22}$ | 202 | 187 | rare | low – mod. |

Key: * Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Assignment of cuparene (S56), calamenene (S59) and 5,6,7,8-tetrahydrocadalene (S75) was achieved by correlation with published mass spectra (Grantham and Douglas, 1980; Philp, 1985; Hostettler *et al.*, 1989).

## D1.5 Saturated tricyclic diterpenoids

Table D1.5 Possible saturated tricyclic diterpenoid compound suite (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| D8 | $C_{20}$ tricyclic diterpane | $C_{20}H_{36}$ | 276 | 191 | common | low - moderate |
| D10 | bisnorditerpane | $C_{18}H_{32}$ | 248 | 135 | uncommon | low - moderate |
| D29.5 | norpimarane | $C_{19}H_{34}$ | 262 | 233 | v. rare † | moderate |
| D31 | $C_{20}$ tricyclic diterpane | $C_{20}H_{36}$ | 276 | 191 | v. rare # + | low |
| D35 | norpimarane | $C_{19}H_{34}$ | 262 | 233 | common | mod. – high |
| D36 | norpimarane | $C_{19}H_{34}$ | 262 | 109/233 | v. rare † | low |
| D45 | norpimarane | $C_{19}H_{34}$ | 262 | 233 | uncommon | low |
| D50 | isopimarane (?) | $C_{20}H_{36}$ | 276 | 163 | common | low – mod. |
| D51 | norabietane | $C_{19}H_{34}$ | 262 | 109 | rare | moderate - high |
| D53 | pimarane/rimuane/unknown | $C_{20}H_{36}$ | 276 | 247 | common # | moderate |
| D54 | pimarane/rimuane/unknown | $C_{20}H_{36}$ | 276 | 247 | uncommon # | moderate – high |
| D55 | pimarane (?) | $C_{20}H_{36}$ | 276 | 247 | v. common | v. high |
| D60 | abietane | $C_{20}H_{36}$ | 276 | 163/276 | common | moderate – high |
| D64 | abietane | $C_{20}H_{36}$ | 276 | 163 | common # | moderate – v. high |
| D70 | $C_{20}$ tricyclic diterpane | $C_{20}H_{36}$ | 276 | 123 | common | low – moderate |
| D71 | $C_{20}$ tricyclic diterpane | $C_{20}H_{36}$ | 276 | 123 | v. rare # + | moderate |
| D76 | $C_{20}$ tricyclic diterpane | $C_{20}H_{36}$ | 276 | 191 | v. rare # | moderate |
| D80 | $C_{20}$ tricyclic diterpane | $C_{20}H_{36}$ | 276 | 191 | uncommon # | high -v. high |

Key: # Indicates detected in the Bowmans Deposit only
† Indicates detected in the Lochiel Deposit only
(?) Indicates tentative assignment
+ Occurs in only one very diterpenoid rich sample
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Two $C_{20}$ compounds D50 and D55 were tentatively identified as isopimarane and pimarane by comparison with published mass spectra (Noble *et al.*, 1986 and Chaffee, 1981, respectively; Figure 2.6). Additional pimarane structures represented by four $C_{19}$ diterpanes (i.e. D29.5, D35, D36 and D45) were interpreted as isomers of norpimarane by comparison to published mass spectra (Chaffee, 1981; Livsey *et al.*, 1984; Philp, 1985).

Three compounds have abietane skeletons, viz. D51, ($C_{19}$), D60 and D64, ($C_{20}$). The latter two were interpreted as isomers of abietane by comparison with published spectra (Chaffee, 1981; Philp, 1985). The $C_{19}$ compound shows a strong *m/z* 109 fragment ion and molecular ion ($M^+$ 262) and was identified as norabietane by comparison with published spectra (Chaffee, 1981; Philp 1985). A tricyclic bisnorditerpane (D10, $M^+$ 248), with base peak of *m/z* 135 remains unassigned. However, it displays a marked similarity to an unnamed compound reported by Philp (1985, mass spectrum # 164).

## D1.6 Tetracyclic diterpenoids

Table D1.6 Possible tetracyclic diterpane compound suite (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| D5 | $C_{18}$ tetracyclic diterpane (?) | $C_{18}H_{30}$ | 246 | 123/217 | rare | low - moderate |
| D52 | *ent* -beyerane | $C_{20}H_{34}$ | 274 | 274 | uncommon # | low |
| D57 | $C_{20}$ tetracyclic (?) | $C_{20}H_{34}$ | 274 | 137 | v. rare # + | moderate |
| D63 | 16α(H)-phyllocladane | $C_{20}H_{34}$ | 274 | 123 | common | mod. – v. high |
| D65 | isomer of *ent* -beyerane (?) | $C_{20}H_{34}$ | 274 | 274 | uncommon | low -moderate |
| D75 | *ent* -16α(H)-kaurane | $C_{20}H_{34}$ | 274 | 123 | common | high |

Key: # Indicates detected in the Bowmans Deposit only
(?) Indicates tentative assignment
+ Occurs in only one very diterpenoid rich sample
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Three tetracyclics have been assigned including *ent* -beyerane, (D52), 16α(H)-phyllocladane (D63) and *ent*-16α(H)-kaurane, (D75) based on comparison with published mass spectra and their elution order (Noble *et al.*, 1985; Noble *et al.*, 1986; Figure 2.6). Spectral features similar to those of *ent*-beyerane were recognised in the compound D65.

## D1.7 Possible diterpenoids with $M^+$ 274 and dominant *m/z* 259 base peak

Table D1.7 $M^+$ 274, *m/z* 259 dominated possible diterpenoids (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| D16 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | rare # | low – mod. |
| D20 | $\Delta^{5,10}$-dihydrorimuene or diastereomer of kaurane | $C_{20}H_{34}$ | 274 | 259 | v. common | mod. - high |
| D21 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | v. rare # + | low |
| D22a | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | v. common | low – mod. |
| D22b | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 /241 | v. common | low |
| D24 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | common | low |
| D26 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | rare # | low |
| D30 | $\Delta^{5,10}$-dihydrorimuene or diastereomer of kaurane | $C_{20}H_{34}$ | 274 | 259 | v. common | low - mod. |
| D38 | $\Delta^{5,10}$-dihydrorimuene or diastereomer of kaurane | $C_{20}H_{34}$ | 274 | 259 | v. common | low - mod. |
| D39.8 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | v. rare # + | low |
| D40 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | common | moderate |
| D41 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | v. rare # + | low |
| D42 | $C_{20}$ diterpene or tetracyclic diterpane | $C_{20}H_{34}$ | 274 | 259 | v. rare # + | low |

Key: # Indicates detected in the Bowmans Deposit only
+ Occurs in only one very diterpenoid-rich sample
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Definitive identifications have not been achieved for any individual members. However, the mass spectra of three compounds (i.e. D20, D30 and D38) show close resemblance to those of a compound detected by Chaffee (1981) and two compounds recognised by Li and Johns (1990) in brown coals. Chaffee (1981) postulated a diastereomer or epimer of kaurane, while Li and Johns (1990) noted a resemblance to $\Delta^{5,10}$-dihyrdrorimuene.

## D1.8 Other $M^+$ 274 possible diterpenoids

Table D1.8 Other $M^+$ 274 possible diterpenoids (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| D15 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 241 | common | low |
| D25.5 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 241/245 | v. rare # + | low |
| D30.5 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 133/259 | v. rare # | low |
| D39.3 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 132 | uncommon | low -moderate |
| D40.5 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 132 | uncommon | moderate |
| D47 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 241 | common | low - moderate |
| D55.4 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 138 | rare # | low |
| D72 | $C_{20}$ diterpene/diterpane | $C_{20}H_{34}$ | 274 | 201 | v. rare # + | low |

Key: # Indicates detected in the Bowmans Deposit only
+ Occurs in only one very diterpenoid-rich sample
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Definitive compound assignment was not possible for any members of the suite and they possibly represent either monounsaturated tricyclic diterpenes, or tetracyclic diterpanes.

## D1.9 Mono/poly-unsaturated and partially aromatised diterpenoids

Table D1.9 Possible mono/poly-unsaturated and partially aromatised diterpenoids (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| D15X | norditerp-triene | $C_{19}H_{28}$ | 256 | 241 | common | mod. - high |
| D25 | sclarene/iso-pimardiene/abiet-diene (?) | $C_{20}H_{32}$ | 272 | 257 | v. common | mod. - high |
| D28 | $C_{19}$ tricyclic diterpene/diene | $C_{19}H_{34}$ | 258 | 243 | v. rare # + | moderate |
| D28.2 | sclarene/iso-pimardiene/abiet-diene (?) | $C_{20}H_{32}$ | 272 | 257 | v. common | low |
| D28.4 | sclarene/iso-pimardiene/abiet-diene (?) | $C_{20}H_{32}$ | 272 | 257 | v. common | low |
| D29 | $C_{20}$ diterpene/diene | $C_{20}H_{32}$ | 272 | 272/119 | v. rare # + | moderate |
| D29.4 | $C_{20}$ diterpene/diene | $C_{20}H_{32}$ | 272 | 119 | v. rare # + | low |
| D29.8 | sclarene/iso-pimardiene/abiet-diene (?) | $C_{20}H_{32}$ | 272 | 257 | v. common | mod. - high |
| D32 | $C_{20}$ diterpene/diene | $C_{20}H_{32}$ | 272 | 121 | v. common | low |
| D38.5 | $C_{20}$ diterpene/diene | $C_{20}H_{32}$ | 272 | 243 | uncommon | low |
| D39 | $C_{20}$ diterpene/diene | $C_{20}H_{32}$ | 272 | 119 | common | low |
| D39.5 | partially aromatised diterpenoid(?) | $C_{20}H_{30}$ | 270 | 132 | v. rare | low |
| D51.5 | sclarene/iso-pimardiene/abiet-diene (?) | $C_{20}H_{32}$ | 272 | 257 | rare | mod. - high |
| D55.2 | sclarene/iso-pimardiene/abiet-diene (?) | $C_{20}H_{32}$ | 272 | 257 | v. common | moderate |
| D56 | sclarene/iso-pimardiene/abiet-diene (?) | $C_{20}H_{32}$ | 272 | 257 | common | low |
| D62 | dehydroabietane | $C_{20}H_{30}$ | 270 | 255 | rare † | low – mod. |
| D70.5 | norditerp-triene | $C_{19}H_{28}$ | 256 | 241 | rare # | moderate |
| D85 | partially aromatised diterpenoid (?) | $C_{20}H_{30}$ | 270 | 118 | uncommon # | low – mod. |

Key: # Indicates detected in the Bowmans Deposit only
† Indicates detected in the Lochiel Deposit only
(?) Indicates tentative assignment
+ Occurs in only one very diterpenoid-rich sample
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

One member (i.e. D62) with a base peak of *m/z* 255 was identified as partially aromatised dehydroabietane by comparison with published mass spectra (Philp, 1985) and the descriptions of Wang and Simoneit (1990).

Definitive identification of other compounds within this group was not achieved. However, a dominant base peak at *m/z* 257 has been reported for scalene (Philp, 1985), while Wang and Simoneit (1990) identified isopimaradiene and abietadiene (each with $M^+$ 272 a base peak at *m/z* 257) in brown coal. Furthermore, the mass spectrum of $\Delta^{5,10}$-rimuene also shows similarities to the spectra observed within this group. Compounds D39.5 and D85 ($M^+$ 270) are possibly partially aromatised, while the two compounds D15X and D70 ($M^+$ 256) display spectral characteristics similar to those of 18-norabiet-8,11,13-triene (Wang and Simoneit, 1990).

## D1.10 Other possible diterpenoids

Table D1.10 Other possible diterpenoids (in elution order)

| Ident-ifier | Compound Designation | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| D48 | norabiet-tetraene (?) | $C_{19}H_{26}$ | 254 | 239 | v. rare † | moderate |
| D90 | simonellite (?) | $C_{19}H_{24}$ | 252 | 237 | rare | low – mod. |

Key: † Indicates detected in the Lochiel Deposit only
(?) Indicates tentative assignment
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Diterpenoids showing similar characteristics to those listed above have been reported by Wang and Simoneit (1990) in brown coal. Compound D48 ($M^+$ 254, base peak m/z 239) is tentatively assigned as norabiet-tetraene. D90 has a strong *m/z* 237 base peak and was tentatively identified as the diaromatic compound simonellite.

## D1.11 Intact terrigenous triterpenoids

Table D1.11 Possible intact terrigenous triterpenoid compound suite (in elution order)

| Peak ID | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Type | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|---|
| H9 | isomer of 24-nor-olean-12-ene (?) | $C_{29}H_{48}$ | 396 | 218 | OL | common | low |
| H28 | olean-2,12-diene | $C_{30}H_{48}$ | 408 | 218 | OL | common | low |
| H28.2 | 24-*nor* -urs-12-ene (?) | $C_{29}H_{48}$ | 396 | 218 | URS | common | v. low - low |
| H33 | olean-13(18)-ene (?) | $C_{30}H_{50}$ | 410 | 218 | OL | common | low |
| H36 | olean-12-ene | $C_{30}H_{50}$ | 410 | 218 | OL | v. common | high – v. high |
| H37 | olean-m,n-diene (?) | $C_{30}H_{48}$ | 408 | 408/189 | OL | uncommon - common | low - moderate |
| H53 | 18α-olean-12-ene (?) | $C_{30}H_{50}$ | 410 | 109 | OL | very rare | high |

Key: (?) indicates tentative compound assignment
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Six regular oleanenes and one ursene have been assigned, although confident identification is limited to the most abundant member, olean-12-ene (H36; Figure 2.6). Olean-2,12-diene (H28) and olean-13(18)-ene (H33) are tentatively assigned based on their correlation with published mass spectra and/or relative elution position (Stout, 1992; ten Haven *et al.*, 1992a). Assignment of the remaining three oleanenes (H37, H53 and H9) is very provisional. H37 has similar characteristics to those of olean-2,18-diene and olean-2,13(18)-diene (ten Haven *et al.*, 1992a), with the former showing the closest match. The relative elution position of H53 suggests its possible identification as 18α-olean-12-ene (ten Haven *et al.*, 1993). The mass spectrum of H9 appears similar to that of 24-*nor*-olean-12-ene (ten Haven *et al.*, 1992b), but its elution position is inconsistent with published reports and an isomer or related oleanene is tentatively suggested.

A very provisional assignment of 24-*nor*-urs-12-ene was made for H28.2, in line with its elution position and mass spectrum (ten Haven *et al.*, 1992b).

## D1.12 A-ring-contracted triterpenoids

Table D1.12 Possible A-ring-contracted triterpadienes and triterpenes (in elution order)

| Peak ID | Compound Assignment | Compos -ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| H8.5 | A-*neo* -nor-triterp-m,n-diene | $C_{29}H_{46}$ | 394 | 190/394 | uncommon | moderate |
| H11a | A-*neo* -nor-triterp-m,n-diene | $C_{29}H_{46}$ | 394 | 351 | v. common | high |
| H15 | A-*neo* -triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 190/408 | v. common | v. high |
| H16 | A-*neo* -olean-3(5),12-diene or A-*neo* -urs-3(5),12-diene | $C_{30}H_{48}$ | 408 | 365 | v. common | v. high |
| H16.2 | A-*neo* -triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 365 | v. common | high |
| H16.8 | A-*neo* -nor-triterp-m,n-diene | $C_{29}H_{46}$ | 394 | 351 | common | high |
| H17.2 | A-*neo* -triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 365 | common | low |
| H17.4 | A-*neo* -triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 365 | v. common | moderate |
| H24 | A-*neo* -triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 365 | common | low |
| H31 | A-*neo* -triterp-m,n-diene | $C_{30}H_{48}$ | 408 | 365 | v. common | high |
| H44.5 | A-*neo* -homo-triterp-m,n-ene | $C_{31}H_{52}$ | 424 | 381 | rare | low |
| H56 | A-*neo* -homo-triterp-m,n-ene | $C_{31}H_{52}$ | 424 | 381 | rare | moderate |

Key: * Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Compound of this suite characteristically show an intense $M^+$ - 43 ion. Molecular weights and spectral features reflecting isopropyl and methyl group loss and $M^+$ - 43 base peaks are best matched by the bicadinanes (van Aarssen *et al.*, 1990a; Peters and Moldowan, 1993) and A-ring contracted compounds (ten Haven *et al.*, 1992a; Killops and Frewin, 1994), although lupanes and fernanes showing some similarities have also been reported (Chaffee, 1981; Rullkotter *et al.*, 1992; Stout, 1992). The widespread occurrence of sesquiterpenoids with a cadalene skeleton in the Lochiel and Bowmans coals, and detection of bicadinanes outside South East Asia (Crelling *et al.*, 1990; Killops *et al.*, 1995), precluded exclusion of bicadinane precursors on the basis that fossil dipterocarps have not yet been reported from Australia.

Ultimately, these twelve compounds were interpreted as A-ring-contracted triterpdienes and triterpenes based on their mass spectral characteristics and relative retention time. Key characteristics included a prominent $M^+$ 365 ion, the presence of several other fragment ions typical of A-ring contacted compounds (i.e. 121, 175, 203, 271, 365, 393 and 408) and an elution position proximal to *n*-$C_{29}$.

Tentative compound assignment is limited to H16, the mass spectrum of which is very similar the published mass spectra of A-*neo*-urs-3(5),12-diene and A-*neo*-olean-3(5),12-diene (ten Haven *et al.*, 1992a), with the former possibly showing a closer match.

## D1.13 Des-A triterpenoids

Table D1.13 Possible des-A triterpenoids (in elution order)

| Ident-ifier | Compound Assignment | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| A20 | | $C_{23}H_{36}$ | 312 | 269 | v. common | high |
| A25 | | $C_{23}H_{36}$ | 312 | 269 | common | high |
| A30 | "A" of Stout (1992) | $C_{24}H_{38}$ | 326 | 326 | v. common | high |
| A32 | | $C_{23}H_{38}$ | 314 | 271 | uncommon | low – mod. |
| A34 | isomer of "A" of Stout (1992) | $C_{24}H_{38}$ | 326 | 326 | rare # | low – mod. |
| A34.5 | | $C_{24}H_{38}$ | 326 | 203/326 | v. rare # | low – mod. |
| A35 | | $C_{22}H_{32}$ | 296 | 199 | rare | low – mod. |
| A36 | possible oleanene series | $C_{24}H_{40}$ | 328 | 313 | rare | low – mod. |
| A38 | | $C_{23}H_{38}$ | 314 | 299 | uncommon # | low – mod. |
| A40a | "C" of Stout (1992) | $C_{24}H_{38}$ | 326 | 326 | common | high |
| A40b | 10αdes-A-olean-13(18)-ene (?) | $C_{24}H_{40}$ | 328 | 109/328 | uncommon | mod - high |
| A41 | | $C_{23}H_{36}$ | 312 | 281 | v. rare # | low – mod. |
| A44 | | $C_{23}H_{36}$ | 312 | 312 | rare # | high |
| A45 | "D" of Stout (1992) | $C_{24}H_{36}$ | 324 | 324 | common | high |
| A46 | | $C_{23}H_{38}$ | 314 | 271 | uncommon # | low – mod. |
| A50a | | $C_{23}H_{38}$ | 314 | 95/191 | rare # | high |
| A50b | | $C_{24}H_{38}$ | 326 | 133/190 | uncommon | low – mod. |
| A60a | des-A-lup-9-ene | $C_{24}H_{40}$ | 328 | 136 | uncommon | low – mod. |
| A60b | "E" of Stout (1992) | $C_{24}H_{38}$ | 326 | 326 | rare | low |
| A65 | | $C_{23}H_{34}$ | 310 | 213 | uncommon | low – mod. |
| A70 | | $C_{24}H_{40}$ | 328 | 312 | uncommon # | low – mod. |
| A72 | | $C_{24}H_{38}$ | 326 | 326 | rare | mod. - high |
| A74 | possible lupene series | $C_{24}H_{40}$ | 328 | 136 | uncommon # | low – mod. |
| A75 | des-A-lupane (tentative) | $C_{24}H_{42}$ | 330 | 109 | v. rare # | low – mod. |
| A80 | possible lupene series, "K" of Stout (1992) | $C_{24}H_{38}$ | 326 | 136 | uncommon # | low – mod. |
| A95 | possible lupene series, "K" of Stout (1992) | $C_{24}H_{38}$ | 326 | 136 | uncommon | high |

Key: # Indicates detected in the Bowmans Deposit only
(?) Indicates tentative assignment
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Tentative identification is limited to 10αdes-A-olean-13(18)-ene (A40b), des-A-lup-9-ene (A60a) and des-A-lupane (A75; Figure 2.6). These compound assignments are based on comparisons with published mass spectra (Logan and Eglinton, 1994; Trendel *et al.*, 1989; Philp, 1985).

Five unidentified compounds have similar mass spectra to those of the unassigned des-A-triterpenoids described by Stout (1992) from Oligocene brown coal. Matched compounds include A30 ("A" from Stout, 1992), A40a ("C"), A45 ("D"), A60b ("E") and A80 or A95 ("K"). Similarities to three $M^+$ 328 compounds with a key ion at *m/z* 313 described by Wang and Simoneit (1990) were also noted.

## D1.14 Hopanoids

Table D1.14 Hopanoids (in elution order)

| Ident-ifier | Compound Designation | Compos-ition | Mol. Wt. | Base Peak | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|
| H10 | 22,29,30-trisnorhop-13(18)-ene | $C_{27}H_{44}$ | 368 | 176 | v. common | moderate |
| H20 | 17β(H)-22,29,30-trisnorhopane | $C_{27}H_{46}$ | 370 | 149 | v. common | mod. - high |
| H30 | 30-norneohop-13(18)-ene | $C_{29}H_{48}$ | 396 | 191 | common | v. low - low |
| H32 | 30-norhop-17(21)-ene (?) | $C_{29}H_{48}$ | 396 | 231 | common | moderate |
| H34 | 17α(H),21β(H)-30-norhopane | $C_{29}H_{50}$ | 398 | 191 | common | v. low - low |
| H45 | hop-17(21)-ene | $C_{30}H_{50}$ | 410 | 367/231 | v. common | high –v. high |
| H50 | 17β(H),21α(H)-30-normoretane | $C_{29}H_{50}$ | 398 | 191/177 | v. common | low |
| H55 | 17α(H),21β(H)-hopane | $C_{30}H_{52}$ | 412 | 191 | v. common | v. low - low |
| H60 | neohop-13(18)-ene | $C_{30}H_{50}$ | 410 | 191 | v. common | moderate |
| H65 | 17β(H),21β(H)-30-norhopane | $C_{29}H_{50}$ | 398 | 177 | v. common | moderate |
| H66 | 17β(H),21α(H)-moretane (?) | $C_{30}H_{52}$ | 412 | unclear | rare | v. low |
| H70 | 22S-17α(H),21β(H)-homohopane | $C_{31}H_{54}$ | 426 | 191 | v. common | v. low |
| H80 | 22R-17α(H),21β(H)-homohopane | $C_{31}H_{54}$ | 426 | 191 | v. common | v. high |
| H85 | 17β(H),21β(H)-hopane | $C_{30}H_{52}$ | 412 | 191 | v. common | low |
| H90 | 17β(H),21α(H)-homomoretane | $C_{31}H_{54}$ | 426 | 205 | v. common | low - mod. |
| H95 | 17β(H),21β(H)-homohopane | $C_{31}H_{54}$ | 426 | 205 | v. common | low - mod. |

Key: (?) Indicates tentative assignment
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

Hopene members were identified by comparison with published mass spectra (Philp, 1985) and relative retention times (Li *et al.*, 1990; Stout, 1992; Kuangzong *et al.*, 1994; Figure 2.6). In the case of H32 (identified as 30-norhop-17(21)-ene), the assignment is tentative.

Identification of the αβ, βα and ββ hopanes is based on published mass spectra (Chaffee, 1981; Philp, 1985) and their relative elution positions (Winkler, 1986). The identifications of H85 as 17β(H),21β(H)-hopane and H66 as 17β(H),21α(H)-moretane are tentative.

## D1.15 Steroids

Table D1.15 Possible sterene and diasterene compound suite (in elution order)

| Ident-ifier | Compound Designation | Compos-ition | Mol. Wt. | Base Peak | Type | Occurrence * | Relative * Abundance |
|---|---|---|---|---|---|---|---|
| I2 | possible isomer of I20 | $C_{29}H_{50}$ | 398 | 257 | diast. | uncommon | low |
| I4 | 20R-diacholestene (?) | $C_{27}H_{46}$ | 370 | 257 | diast. | common | low – mod. |
| I10 | possible isomer of I20 | $C_{29}H_{50}$ | 398 | 257 | diast. | common | low |
| I20 | 24-ethyl-diacholest-13(17)-ene | $C_{29}H_{50}$ | 398 | 257 | diast. | v. common | high |
| I40 | possible isomer of I20 | $C_{29}H_{50}$ | 398 | 257 | diast. | common | low – mod. |
| I45 | 24R-24-ethylcholest-4-ene | $C_{29}H_{50}$ | 398 | 398 | sterene | mod. common | mod. – high |
| I50 | possible $C_{29}$ sterene | $C_{29}H_{50}$ | 398 | 398 | sterene | uncommon | low - high |

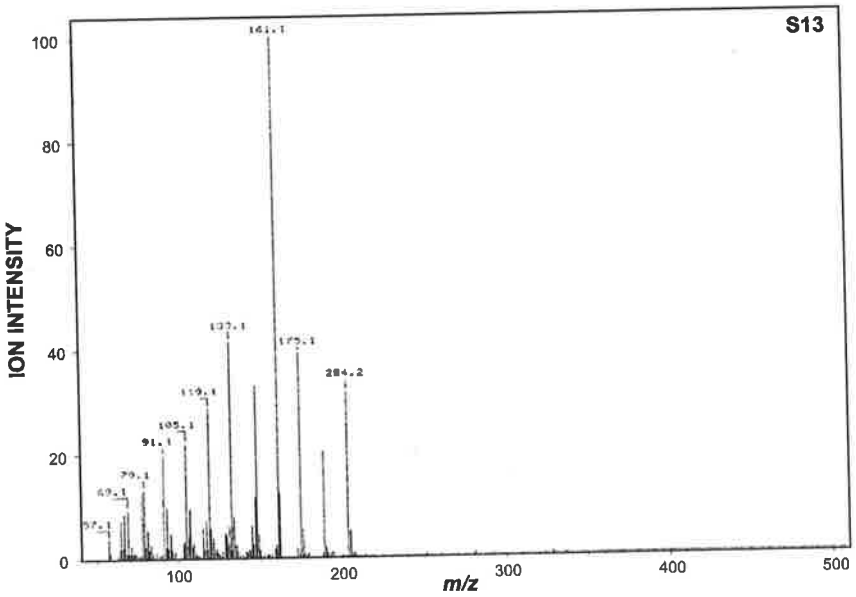
Key: (?) Indicates tentative assignment; diast. = diasterene
* Differences in occurrence and relative abundance may occur between the Lochiel and Bowmans Deposit coals. Where variations occur the classification reflects the deposit showing the most frequent occurrence/ highest relative abundance.

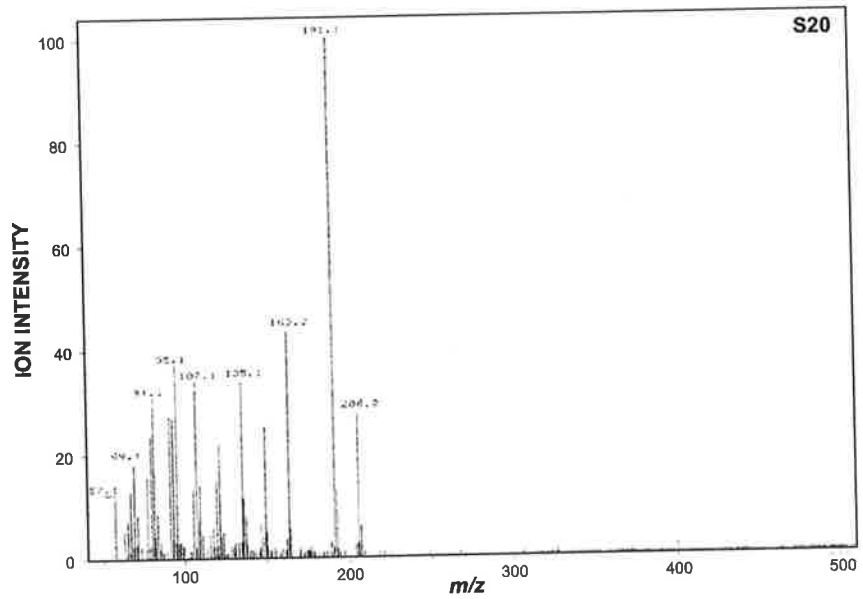
The dominant diasterene (I20) has been identified as 24-ethyl-diacholest-13(17)-ene by comparison to published mass spectral data (Philp, 1985; Figure 2.6). Other diasterenes (i.e. I2, I10 and I40) have similar mass spectra, with a very dominant *m/z* 257 base peak and are possibly isomers of this compound. The diasterene (I4) has been tentatively identified as 20R-diacholestene based on the similarity of its mass spectrum to the published mass spectrum (Philp, 1985). Of the sterenes, I45 shows a close resemblance to the published mass spectrum of 24R-24-ethylcholest-4-ene (Philp, 1985).

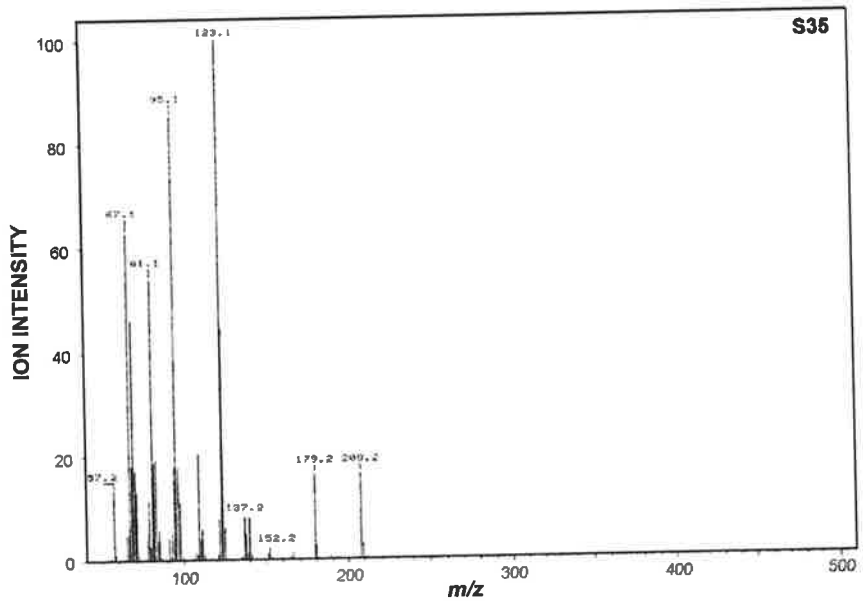
# APPENDIX D2
# REPRESENTATIVE MASS SPECTRA OF MAJOR COMPOUNDS

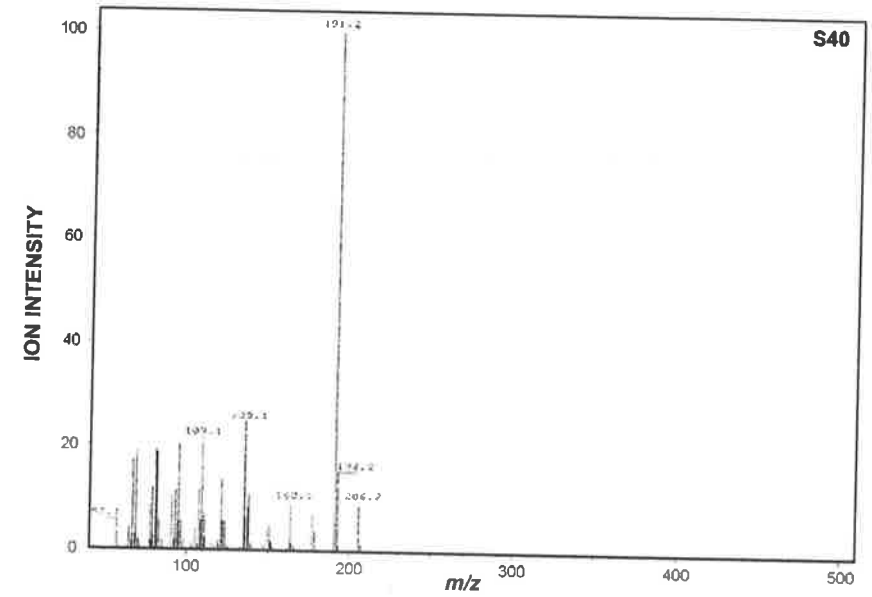
Representative mass spectra for each of the major saturate biomarkers (defined in line with concentration and frequency of occurrence, see Section 8) are presented in Appendix D2, in elution order.

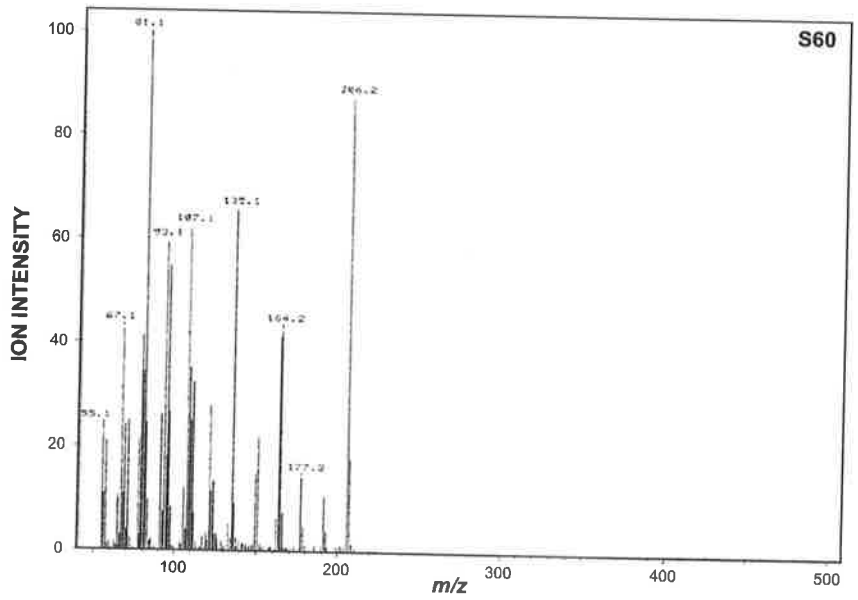
Compound characteristics and possible assignments are outlined in Appendix D1.

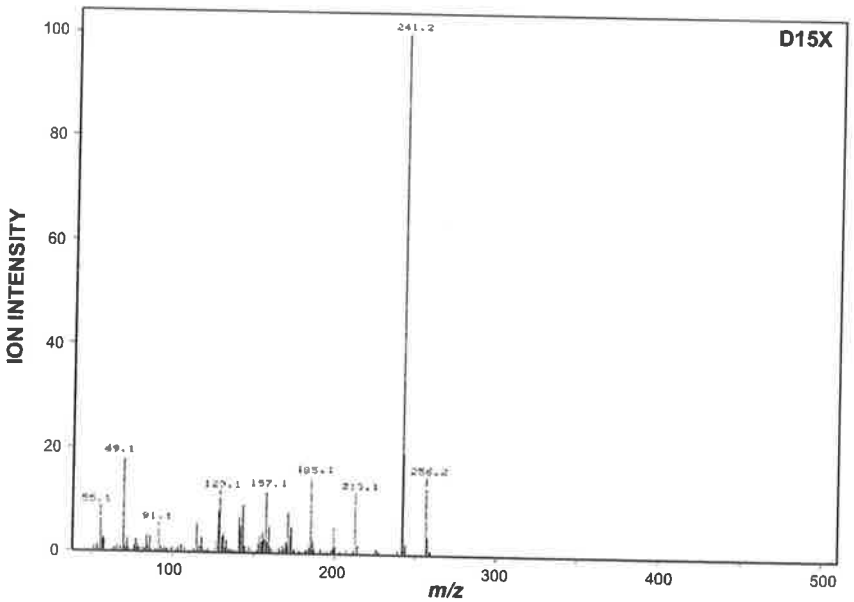

S13
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
161.1
133.1
175.1
284.2
119.1
105.1
91.1
79.1
69.1
57.1

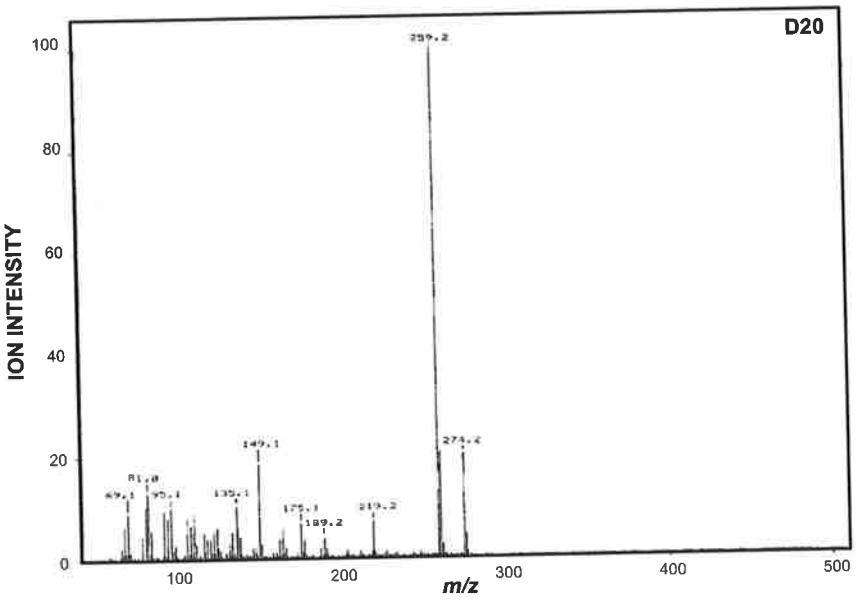

S20
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
191.1
163.2
95.1
107.1
135.1
81.1
206.2
69.1
57.1

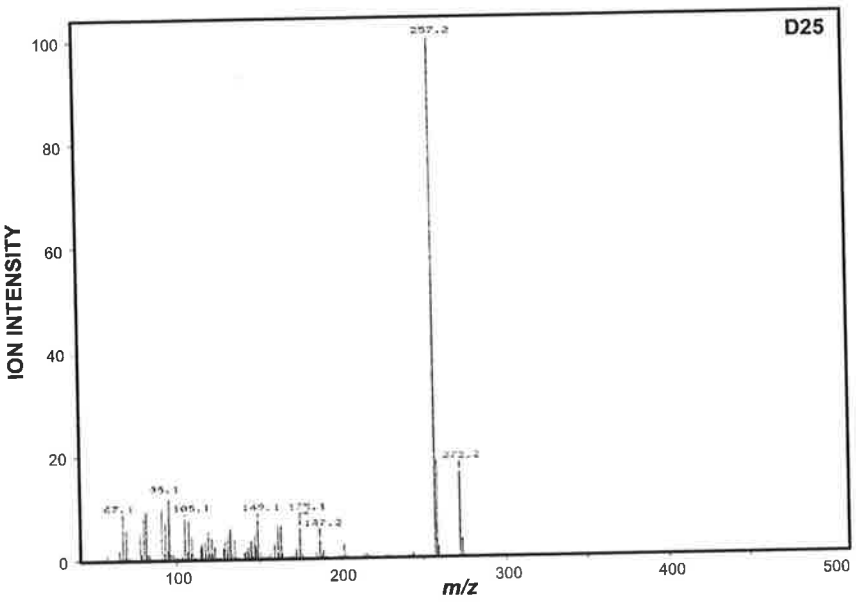

S35
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
123.1
95.1
67.1
81.1
179.2
209.2
57.2
137.2
152.2

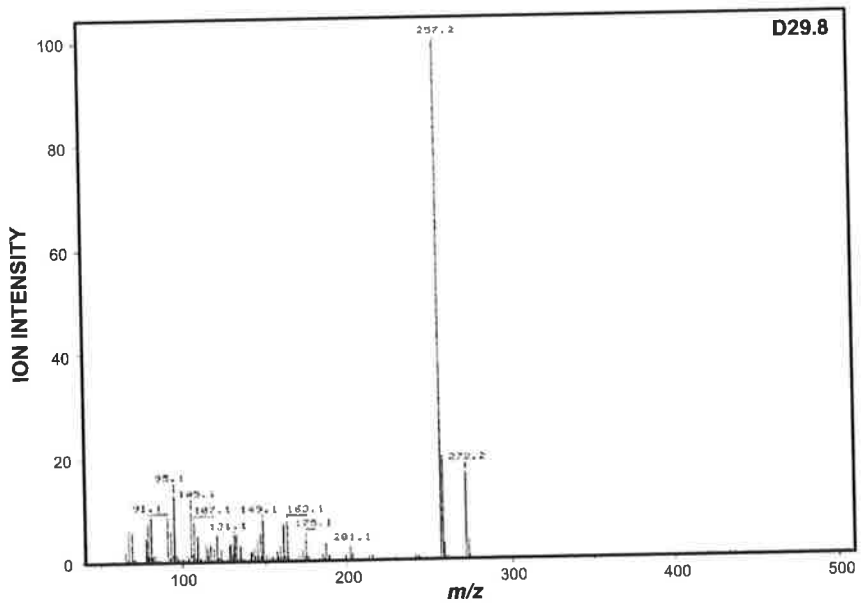

S40
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

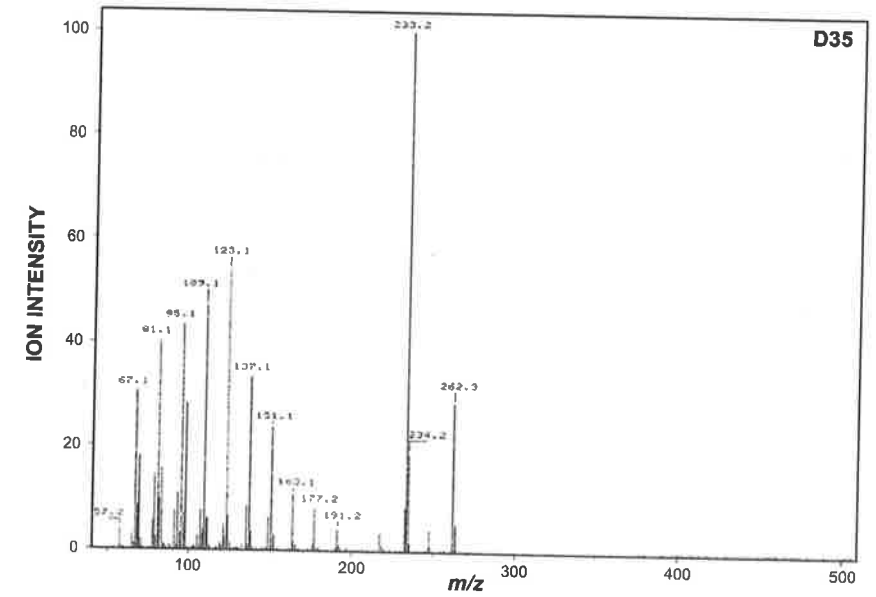

S60
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

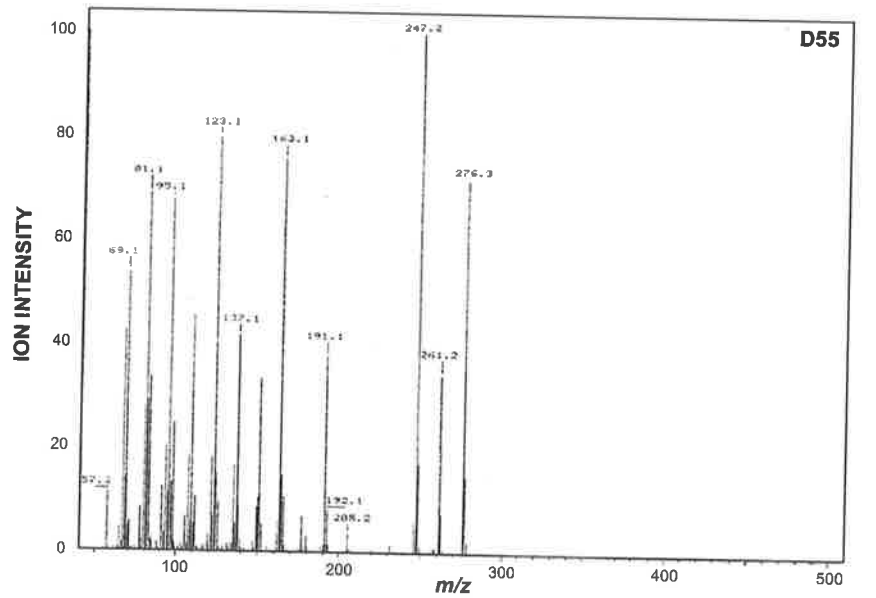

D15X
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

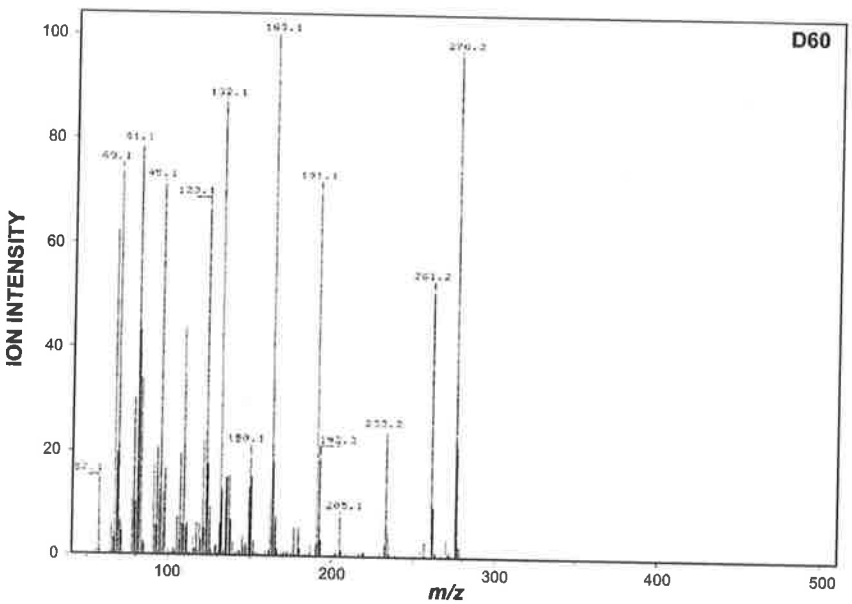

D20
ION INTENSITY
m/z
259.2
149.1
271.2
81.0
69.1
95.1
135.1
175.1
189.2
219.2
100
80
60
40
20
0
100
200
300
400
500

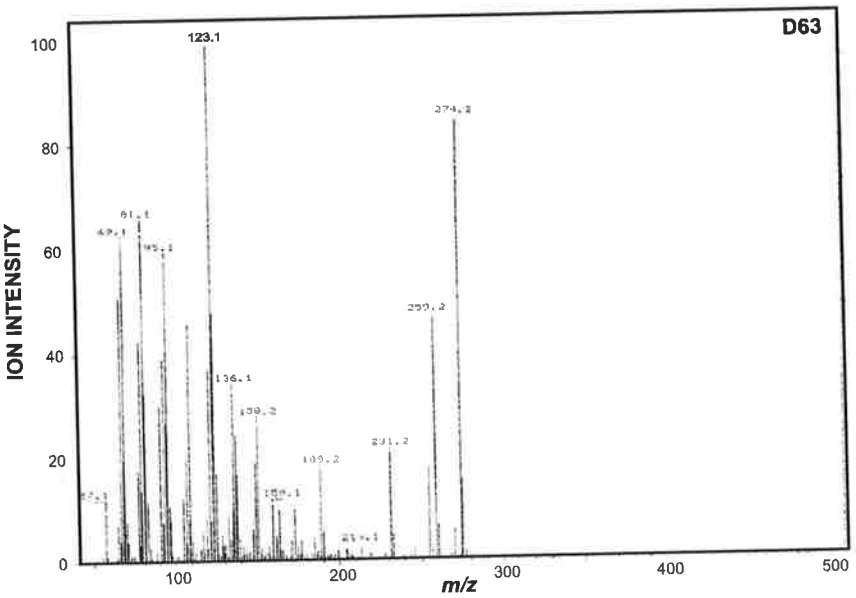

D25
ION INTENSITY
m/z
257.2
272.2
55.1
67.1
105.1
149.1
175.1
187.2
100
80
60
40
20
0
100
200
300
400
500

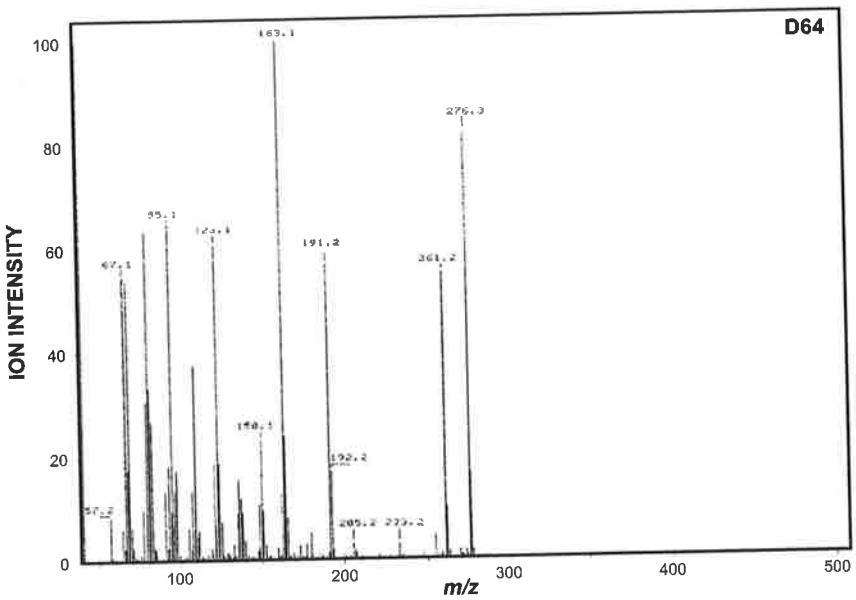

D29.8
ION INTENSITY
m/z
257.2
272.2
95.1
145.1
91.1
107.1
149.1
163.1
121.1
175.1
201.1
100
80
60
40
20
0
100
200
300
400
500

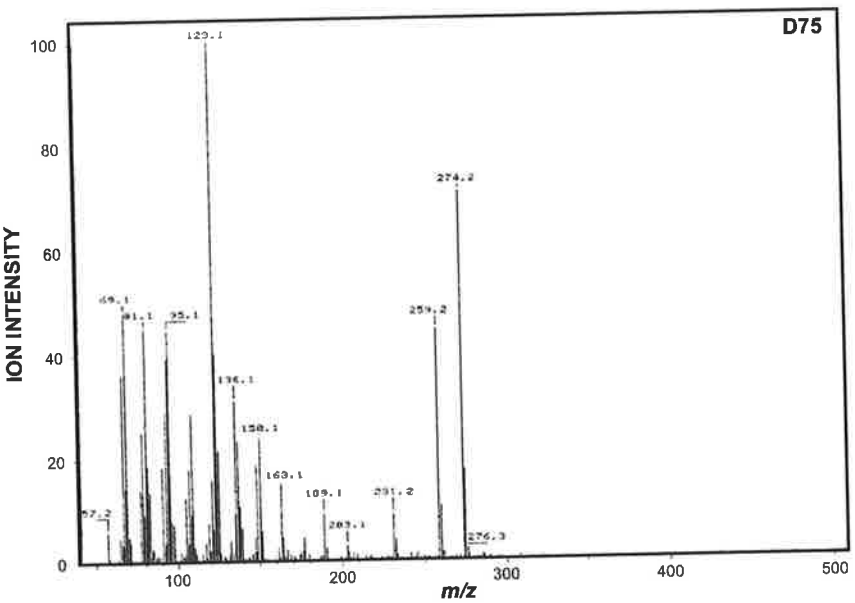

D35
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
233.2
123.1
109.1
95.1
91.1
137.1
67.1
262.3
151.1
234.2
163.1
177.2
191.2

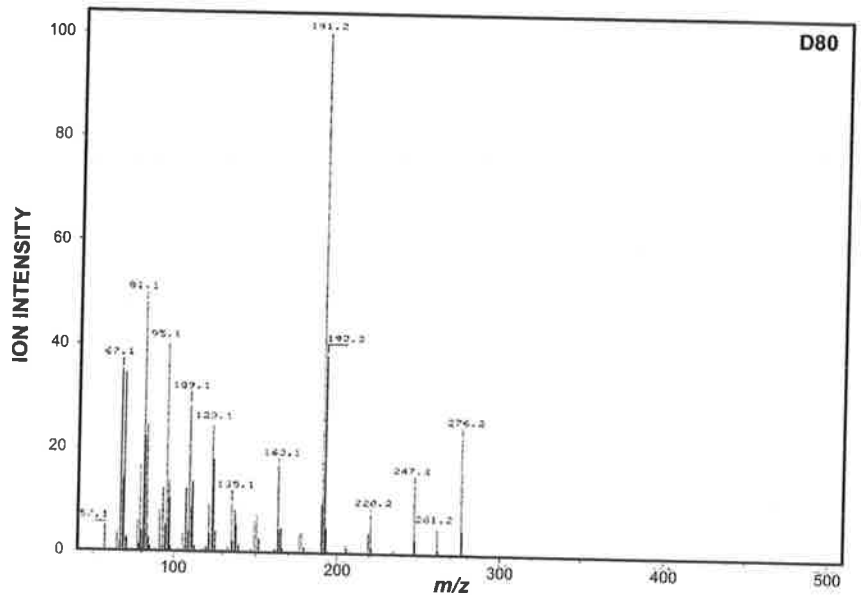

D55
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
247.2
123.1
163.1
276.3
81.1
95.1
69.1
137.1
191.1
261.2
57.1
132.1
208.2

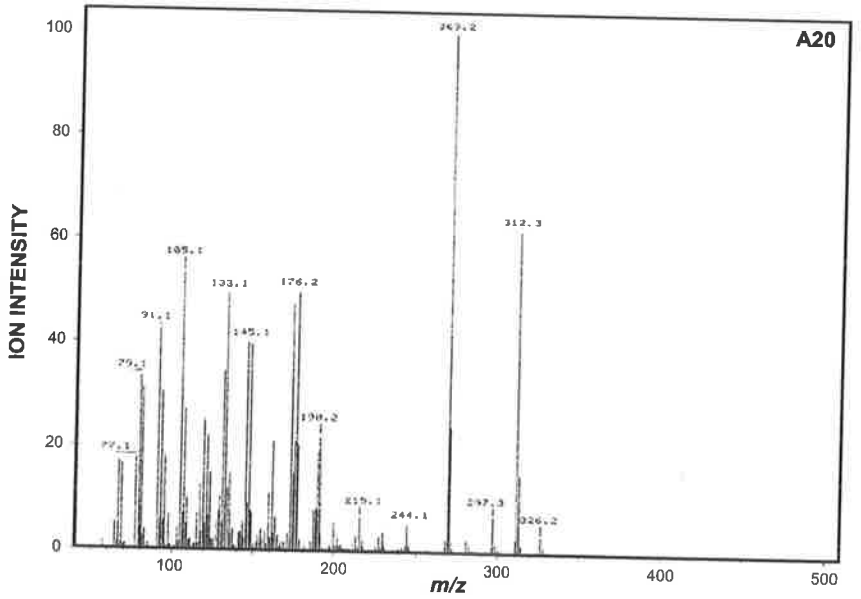

D60
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
163.1
276.2
132.1
81.1
69.1
95.1
123.1
191.1
261.2
150.1
233.2
205.1

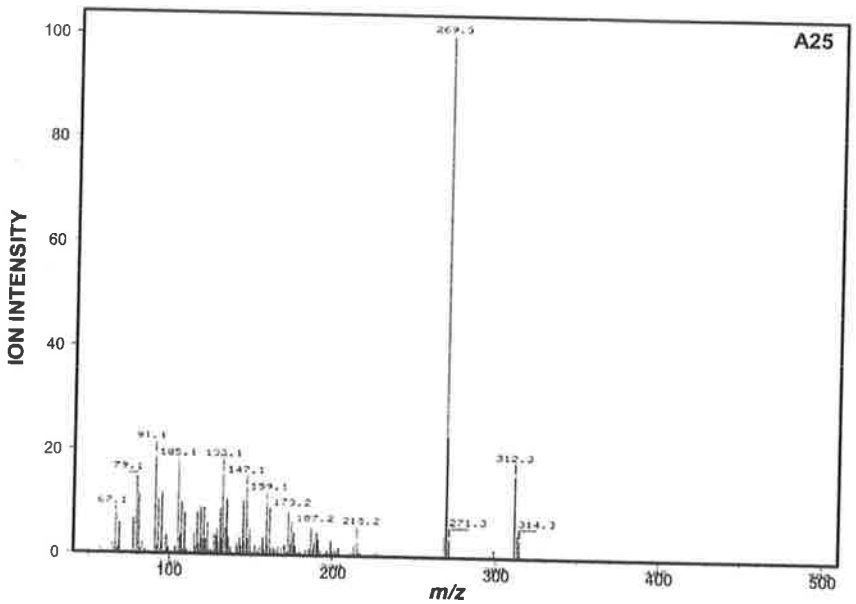

D63
ION INTENSITY
m/z
123.1
274.2
259.2
136.1
231.2
109.2
100
80
60
40
20
0
100
200
300
400
500

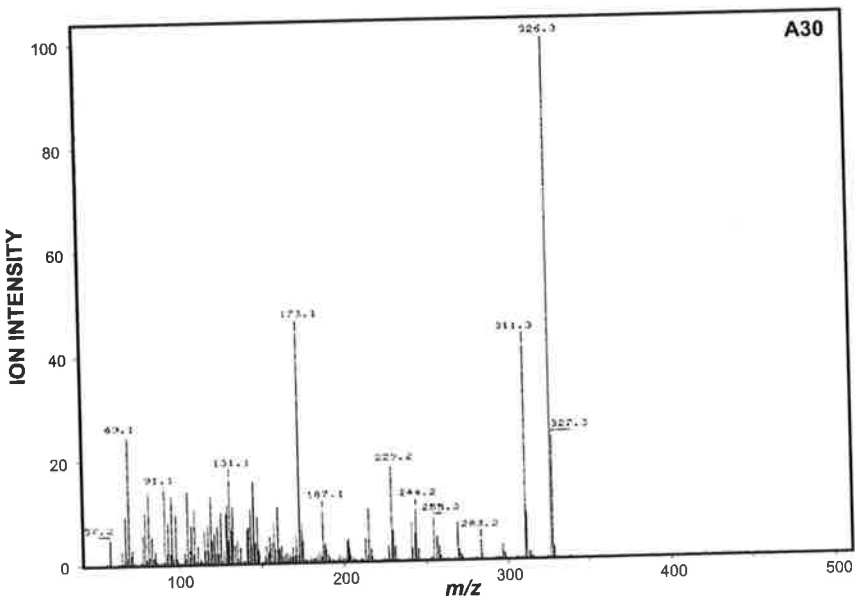

D64
ION INTENSITY
m/z
163.1
276.3
191.2
261.2
95.1
67.1
150.1
192.2
100
80
60
40
20
0
100
200
300
400
500

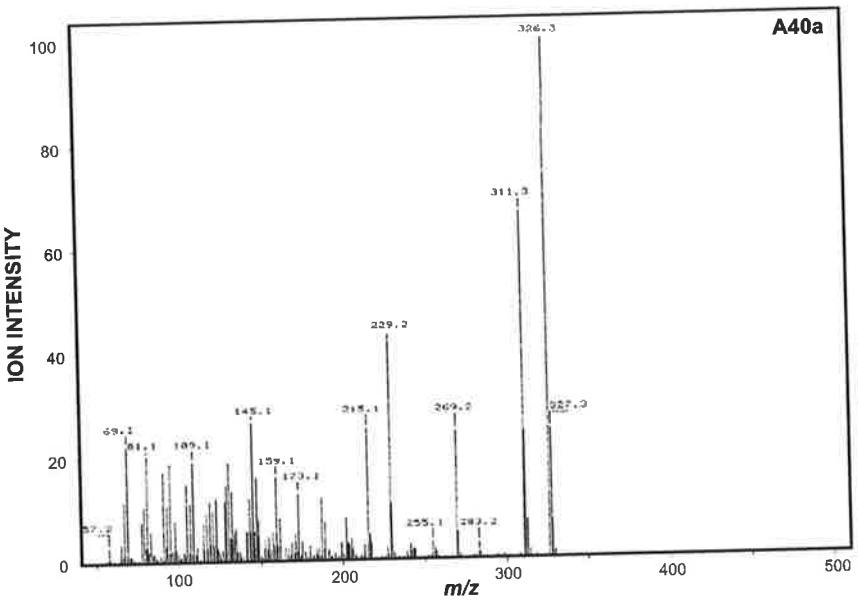

D75
ION INTENSITY
m/z
123.1
274.2
259.2
136.1
158.1
163.1
95.1
81.1
69.1
109.1
291.2
276.3
100
80
60
40
20
0
100
200
300
400
500

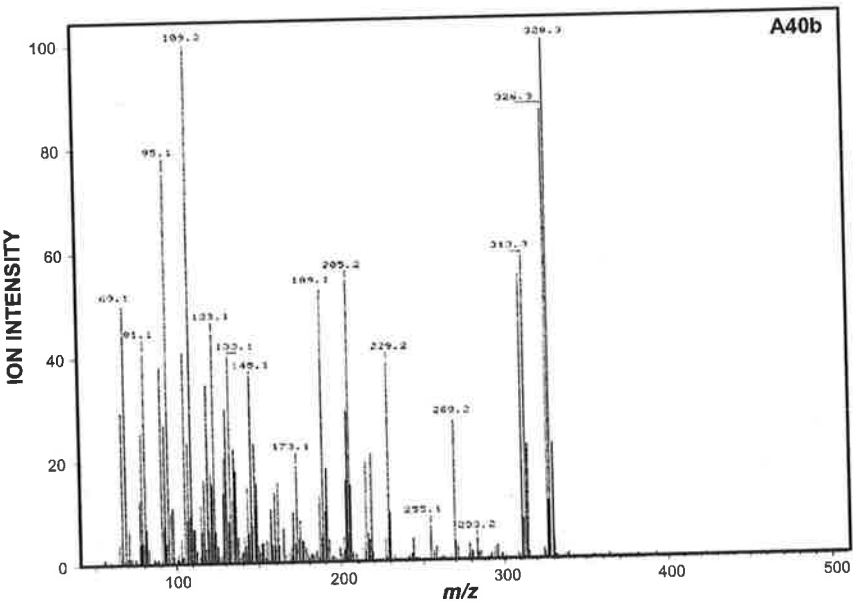

D80
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
191.2
91.1
95.1
67.1
107.1
123.1
163.1
135.1
192.2
220.2
247.1
276.2
281.2

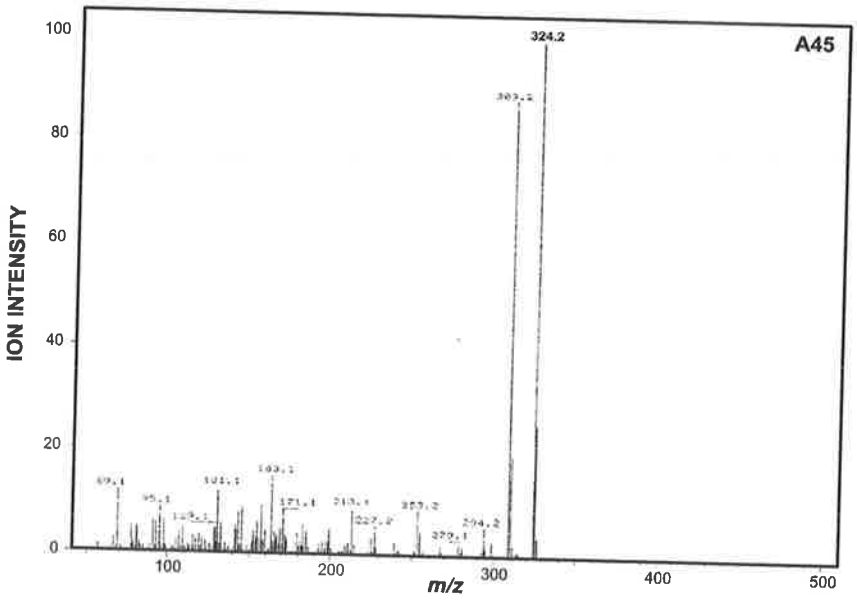

A20
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
269.2
312.3
105.1
133.1
176.2
91.1
145.1
79.1
190.2
77.1
215.1
244.1
297.3
326.2

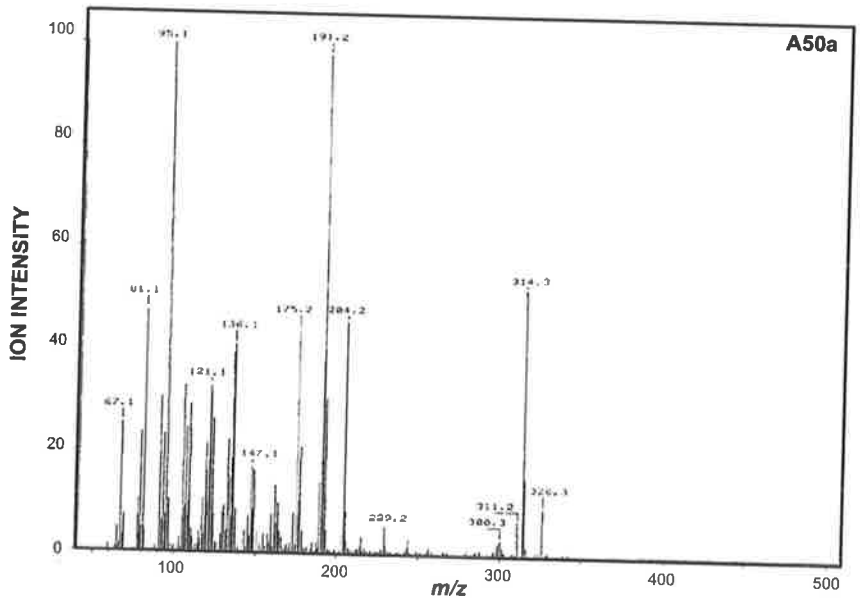

A25
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
269.3
91.1
105.1
133.1
79.1
147.1
159.1
67.1
173.2
187.2
215.2
271.3
312.3
314.3

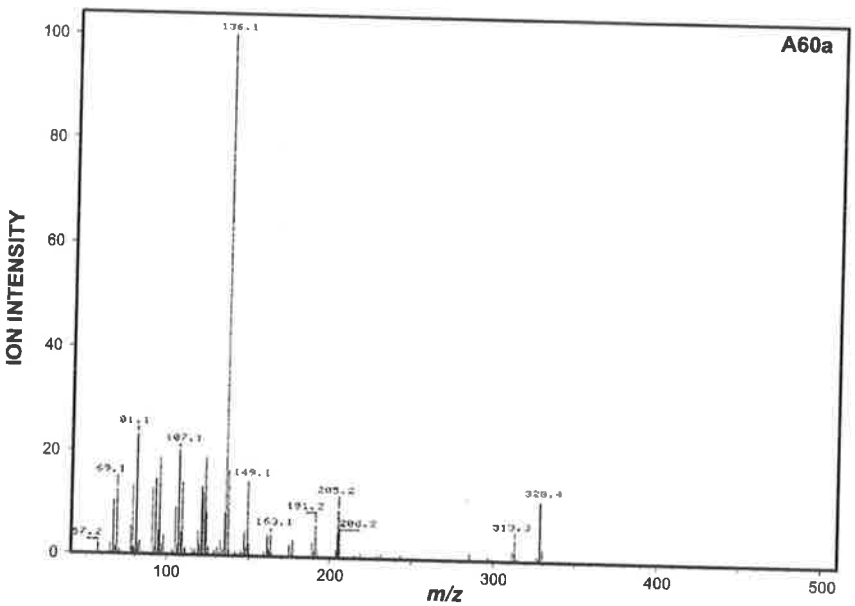

A30
ION INTENSITY
m/z
326.3
311.3
327.3
173.1
229.2
69.1
91.1
131.1
187.1
244.2
255.2
283.2
100
200
300
400
500
0
20
40
60
80
100

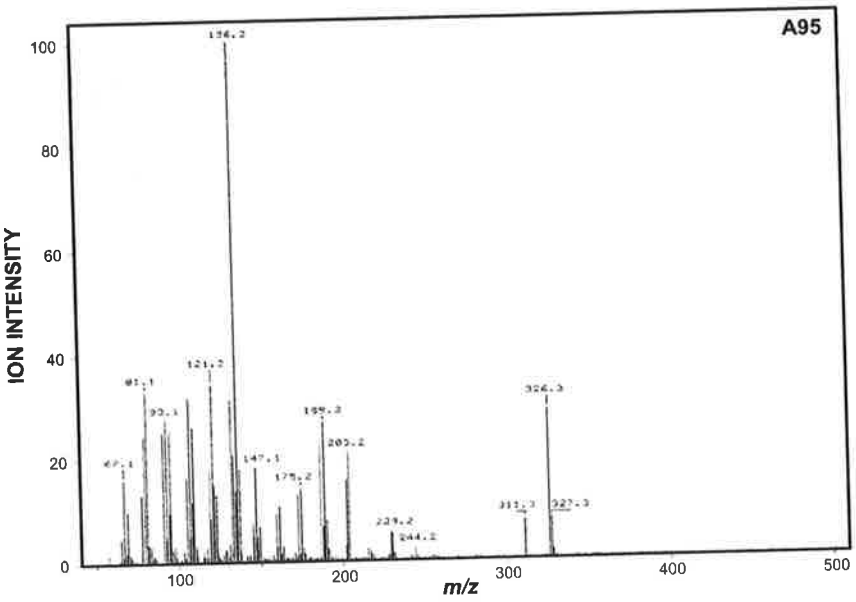

A40a
ION INTENSITY
m/z
326.3
311.3
229.2
327.3
269.2
145.1
315.1
69.1
81.1
109.1
159.1
173.1
255.1
283.2
100
200
300
400
500
0
20
40
60
80
100

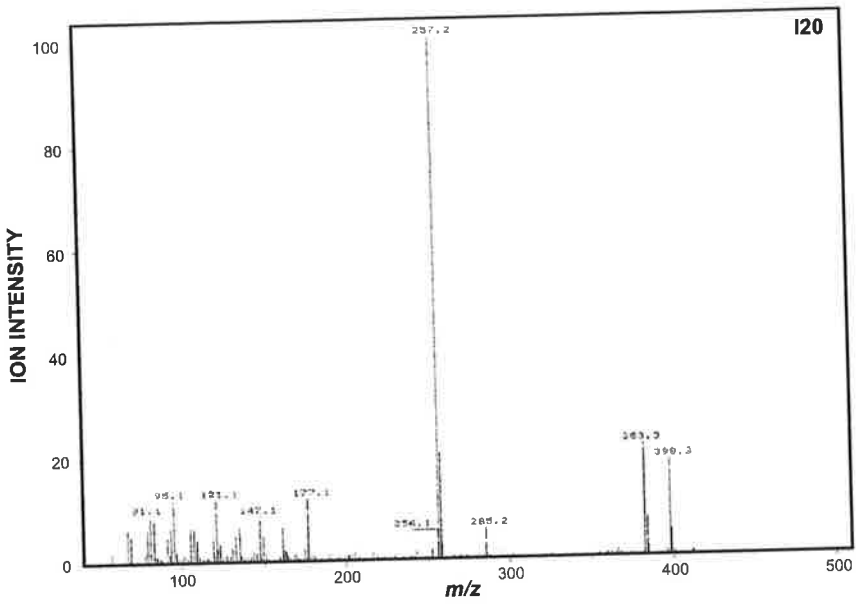

A40b
ION INTENSITY
m/z
109.2
329.3
326.3
95.1
313.3
205.2
69.1
81.1
133.1
132.1
145.1
229.2
269.2
173.1
255.1
283.2
100
200
300
400
500
0
20
40
60
80
100

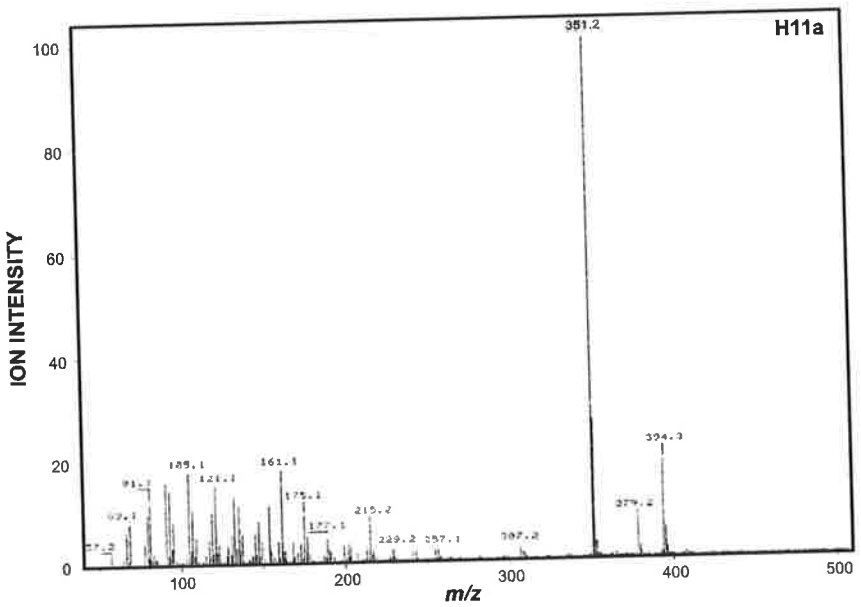

A45
ION INTENSITY
m/z
324.2

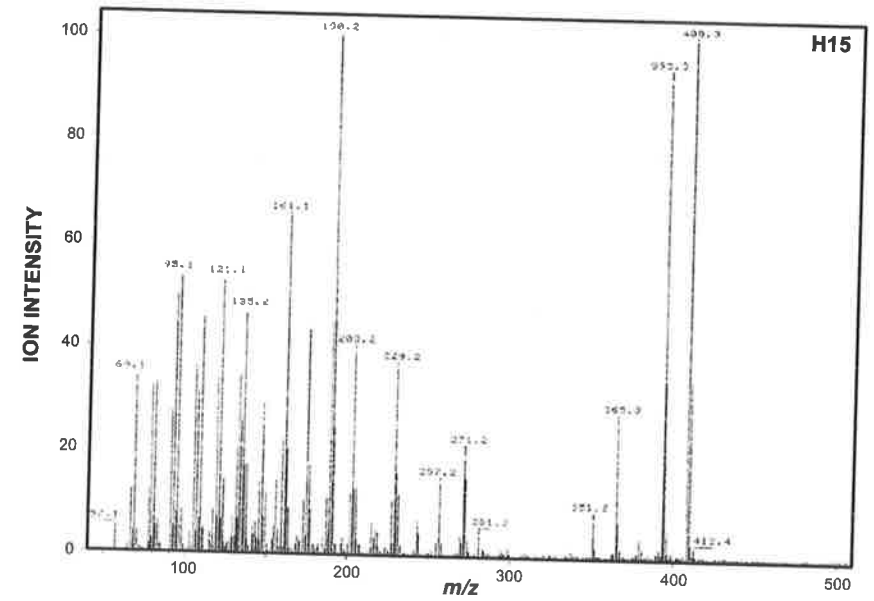

A50a
ION INTENSITY
m/z
95.1
191.2
314.3

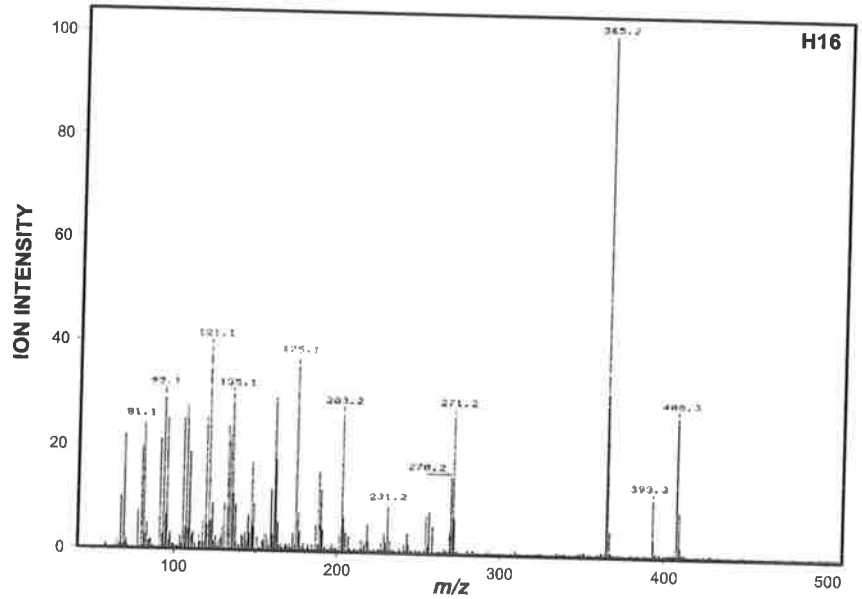

A60a
ION INTENSITY
m/z
136.1

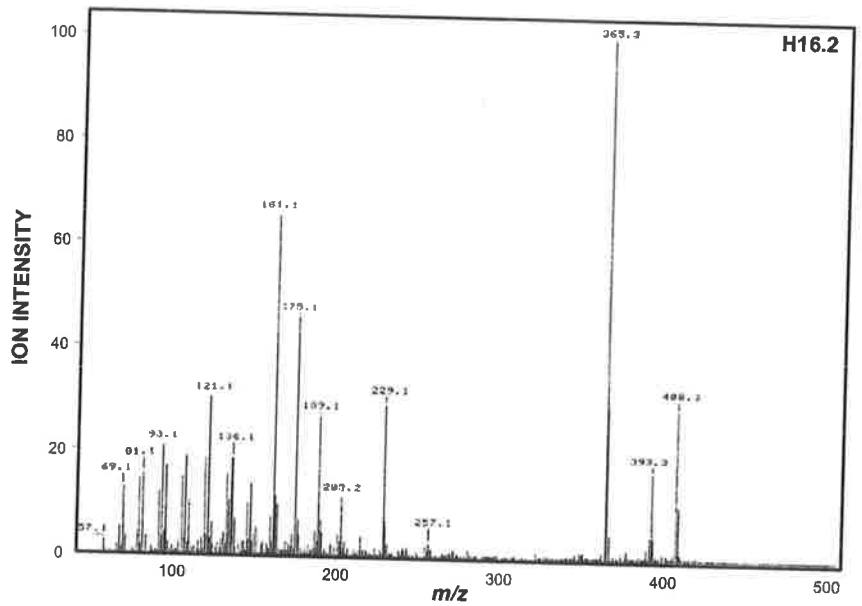

A95
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
134.2
121.2
326.3
165.2
205.2
147.1
175.2
229.2
244.2
311.3
327.3

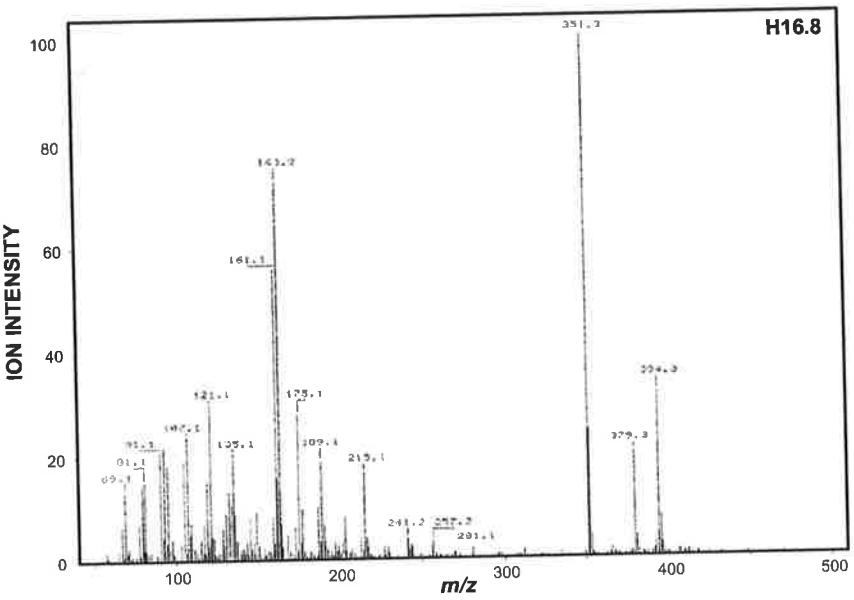

I20
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
257.2
363.3
390.3
285.2

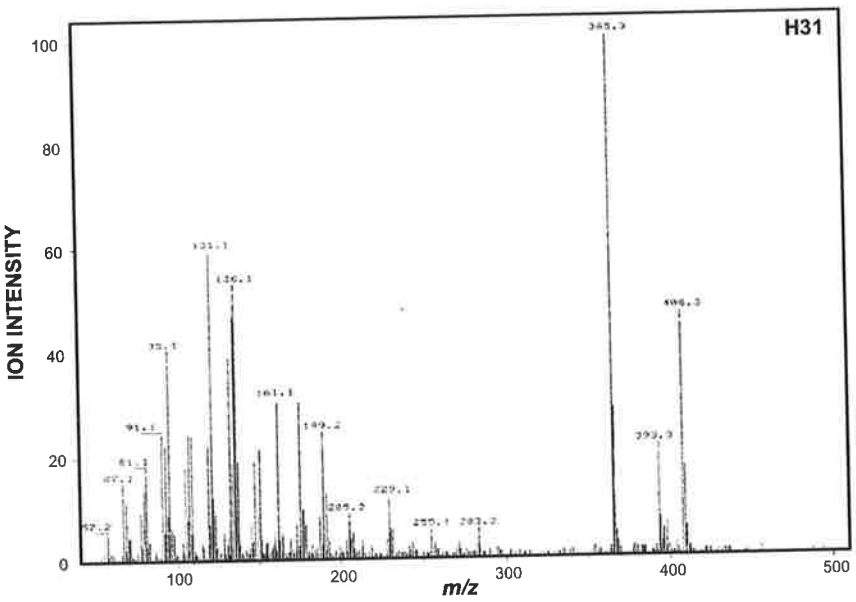

H11a
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
351.2
394.3
185.1
161.1
215.2
229.2
337.1
307.2

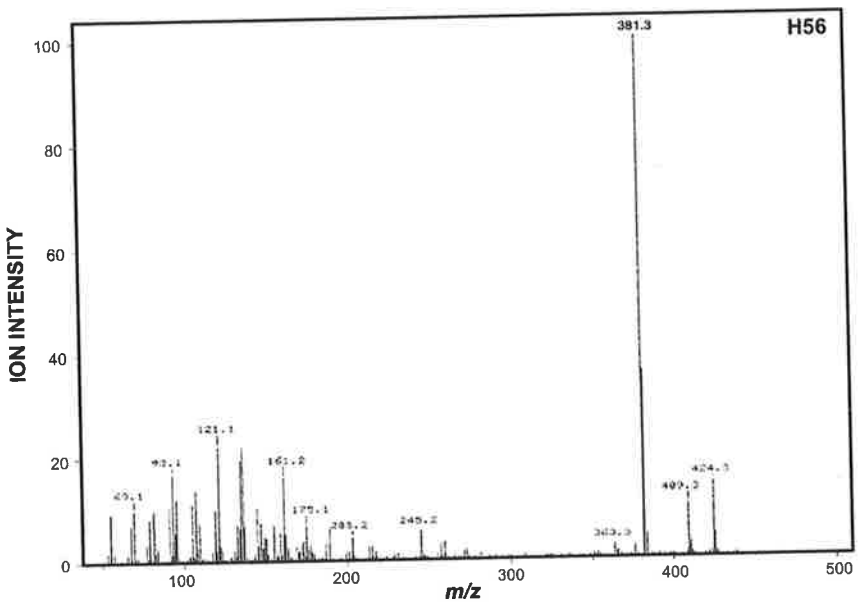

H15
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

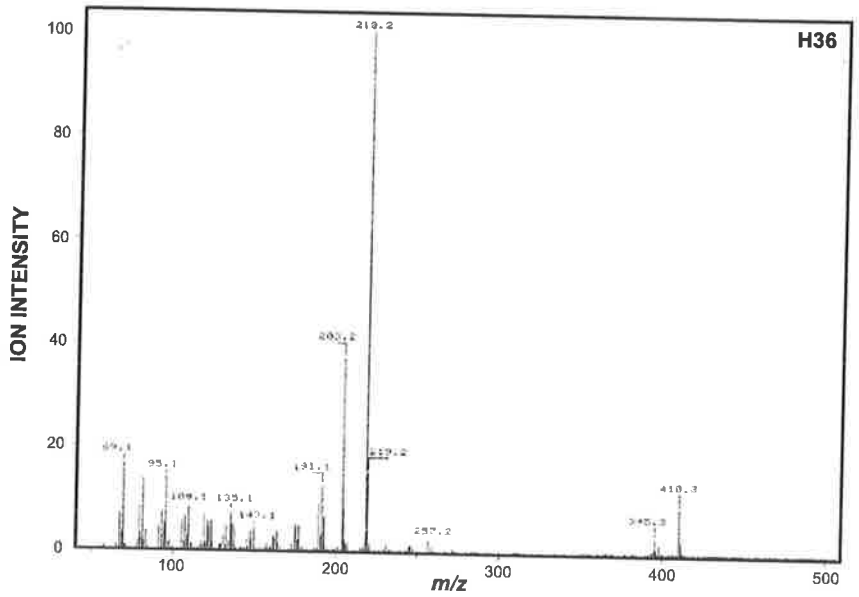

H16
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

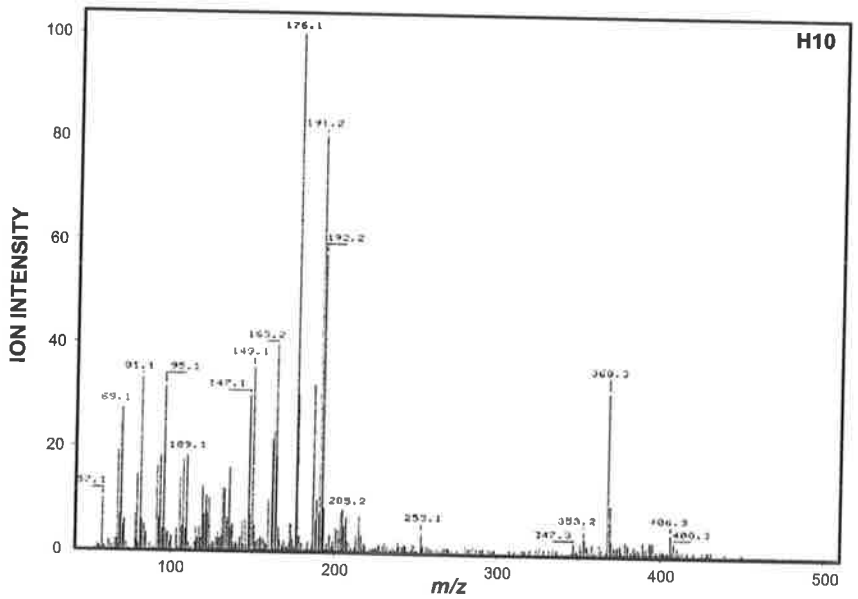

H16.2
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

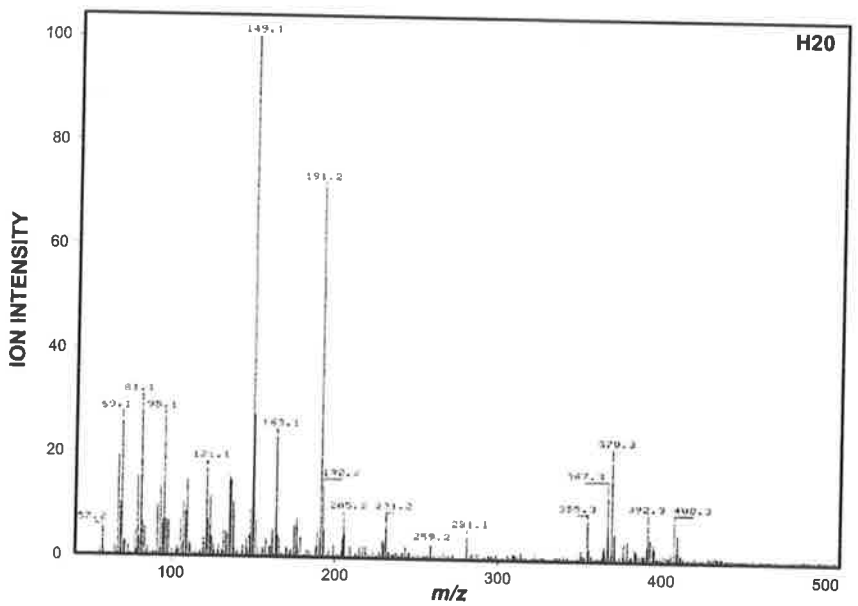

H16.8
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

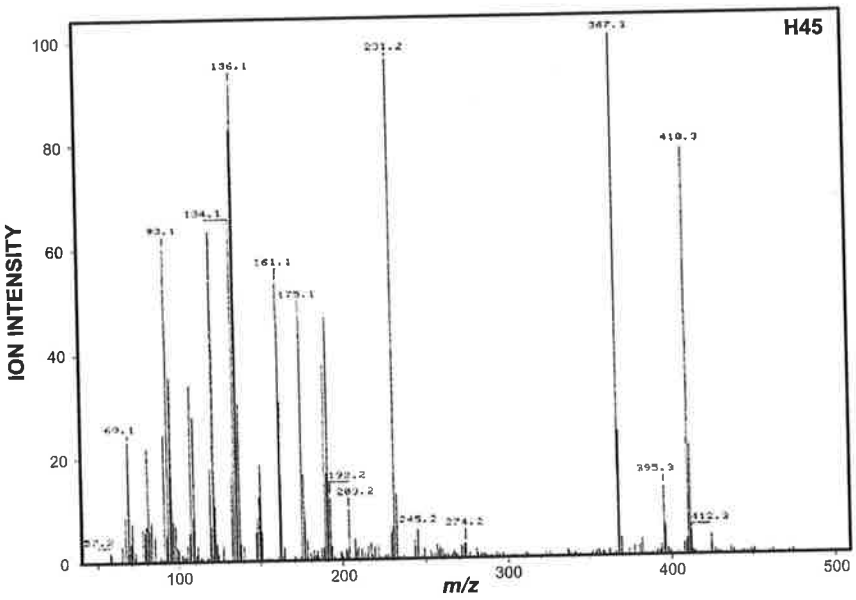

H31
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

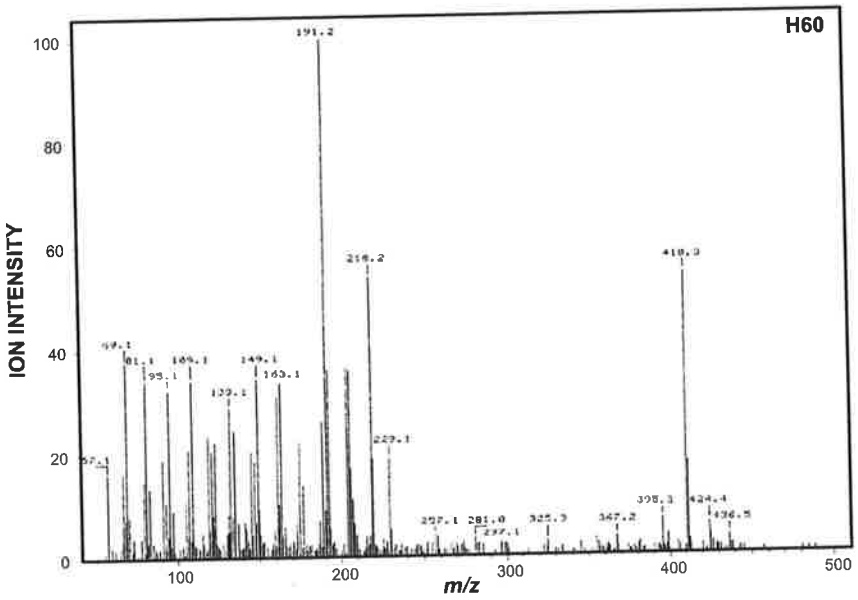

H56
381.3
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500

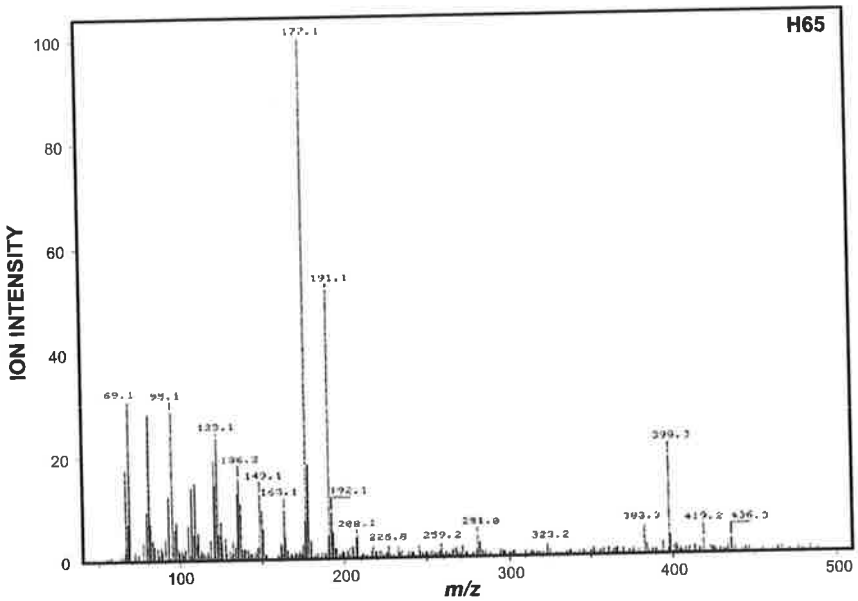

H36
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
219.2
203.2
95.1
131.1
410.3

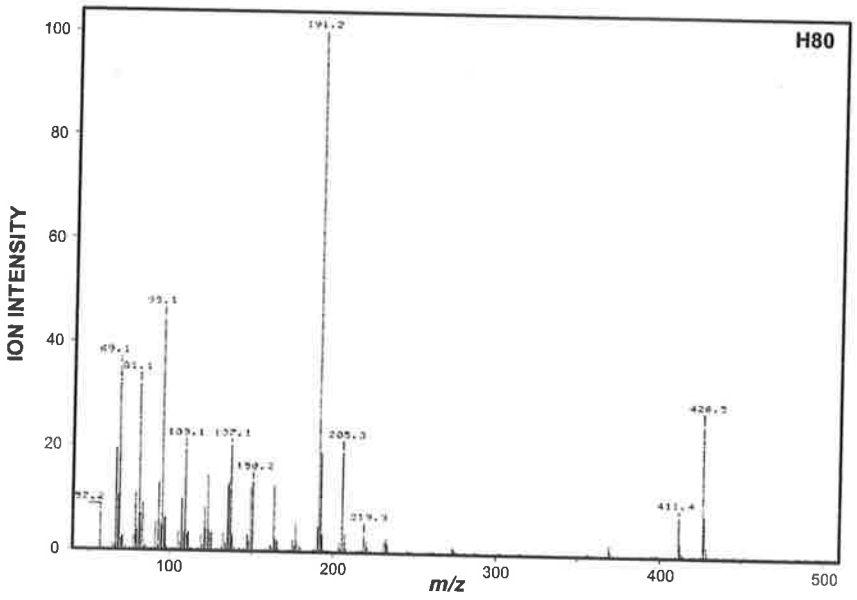

H10
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
176.1
191.2
193.2
165.2
149.1
91.1
95.1
147.1
69.1
169.1
369.3
205.2
253.1
385.2
406.3


H20
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
149.1
191.2
83.1
95.1
165.1
379.3
147.3
205.2
231.2
259.2
291.1
355.3
392.3
408.3


H45
ION INTENSITY
m/z
136.1
231.2
347.3
410.3
93.1
134.1
161.1
175.1
69.1
192.2
209.2
245.2
274.2
395.3
412.3
57.2


H60
ION INTENSITY
m/z
191.2
216.2
410.3
69.1
81.1
95.1
109.1
122.1
149.1
163.1
229.1
57.1
338.3
424.4
436.5
257.1
281.0
297.1
325.3
347.2


H65
ION INTENSITY
m/z
177.1
191.1
69.1
95.1
122.1
136.2
149.1
163.1
192.1
208.1
225.8
259.2
281.0
323.2
399.3
393.2
419.2
436.3


H80
ION INTENSITY
m/z
100
80
60
40
20
0
100
200
300
400
500
191.2
95.1
69.1
81.1
107.1
137.1
150.2
205.3
219.3
411.4
426.3
57.2

# APPENDIX D3
# BIOMARKER EVALUATION
# GC-MS PEAK MEASUREMENT AND RCI ESTIMATION

Raw data collected during GC-MS evaluation, for each of the named and correlated compounds recognised during the research, is presented in this Appendix. In addition data used for estimation of Relative Concentration Index and the index values are included.

Procedures, data and RCI estimates are presented in a series of compound class specific files (Appendix D3.1 to D3.9).

| | |
|---|---|
| Appendix D3.1 | Relative concentration index derivation and application |
| Appendix D3.2 | GC-MS normal alkane peak measurement and RCI estimation |
| Appendix D3.3 | GC-MS sesquiterpenoid peak measurement and RCI estimation |
| Appendix D3.4 | GC-MS diterpenoid peak measurement and RCI estimation |
| Appendix D3.5 | GC-MS regular terrigenous triterpenoid peak measurement and RCI estimation |
| Appendix D3.6 | GC-MS A-ring contracted triterpenoid peak measurement and RCI estimation |
| Appendix D3.7 | GC-MS des-A triterpenoid peak measurement and RCI estimation |
| Appendix D3.8 | GC-MS hopanoid peak measurement and RCI estimation |
| Appendix D3.9 | GC-MS steroid peak measurement and RCI estimation |

# APPENDIX D3.1
# RELATIVE CONCENTRATION INDEX; DERIVATION AND APPLICATION

A precise measure of absolute biomarker abundance was not available for compounds identified during this study. However, a semi-qualitative assessment of relative compound abundance was possible using extract and aliphatic fraction yields, solvent concentrations, sample injection volume and GC-MS response. From this a relative concentration index (RCI) was developed.

The specific objective of RCI estimation was to facilitate a comparison of biomarker abundance, (i.e. individual biomarkers, or a group of related compounds such as tetracyclic diterpenoids) across the sample suite. From this, variations in their relative abundance could be assessed between coal facies and deposits. However, this technique is not suitable for direct comparison of abundance between differing biomarker compound groups or concentrations determined in other brown coal evaluations.

The procedure used to estimate RCI is based on the principles outlined by A. Chaffee (pers. comm., 2001) as follows:

RCI = [ (extract yield x aliphatic yield) / (solvent conc. x injection volume) ] x [(peak height mm on *m/z*=abc trace/ full scale height mm on *m/z*=abc trace) x full scale value total counts on *m/z*=abc trace]

*Where:*

*Extract yield = weight % EOM (extractable organic matter)*

*Aliphatic yield = % aliphatics in EOM*

*Solvent concentration (mg/mm) = mg of aliphatic fraction / solvent height (within standard vial)*

*Injection volume = amount of solvent injected into GC-MS in µl*

*Peak height = peak height in mm above base of mass chromatogram*

*Full scale height = full scale response in mm on mass chromatogram*

*Full scale value = full scale counts on mass chromatogram*

*abc = m/z of mass chromatogram (refer Table D3.1)*

The index consists of three distinct components. The first two relate to sample characteristics and aim to normalise all aspects of sample preparation. In particular, extract and aliphatic yield (which reflect the differing hydrocarbon abundances within the coal and aliphatic fractions) and solvent concentration and injection volume (to standardise for the amount of

aliphatic injected for GC-MS evaluation). The remaining portion of the index deals with the response values measured from the GC-MS trace.

For evaluation of relative facies abundance and interdeposit assessment a normalised RCI was also generated, whereby values for each compound or group were expressed as a percentage of the largest value within the set. The normalised values are reported in tabulations within Chapter 8. Data manipulation for graphical presentation uses raw count data, (i.e. pre-normalised values).

RCI has been estimated for each of the major compound groups, namely *n*-alkanes, sesquiterpenoids, diterpenoids, non-hopanoid triterpenoids (including intact, A-ring contracted and des-A fractions), hopanoids and steroids, as well as assorted subsets and in some cases individual compounds present in high abundance. The specific compounds and ions used to derive RCI are summarised in Table D3.1.

Table D3.1 Compounds and ions used for RCI estimation

| Biomarker | Compound and Ions |
|---|---|
| ***n*-alkanes** | ($n$-$C_{21}$ to $n$-$C_{33}$)$_{m/z\ 99}$ |
| **Sesquiterpenoids** | |
| Major/significant | (S10+S12+S35+S40)$_{m/z\ 123}$ + (S11+S13+S31+S39.8)$_{m/z\ 204}$ + (S10.5+S20+S55+S60)$_{m/z\ 206}$ + (S25)$_{m/z\ 208}$ |
| Saturated | (S10+S21+S35+S43+S45+S57+S70a) $_{m/z\ 123}$ + (S25+S33+S36+S36.5+S54+S67+S72) $_{m/z\ 208}$ |
| Mono-unsaturated | (S9+S15+S34+S37+S40+S50) $_{m/z\ 123}$ + (S10.5+S14+S20+S34.5+S40+S40.7+S43.5+S44+S47+S55+S56.5+S60+S66) $_{m/z\ 206}$ |
| Di-unsaturated | (S11+S13+S13.5+S14.5+S31+S39.8+S52+S58+S70b+S73) $_{m/z\ 204}$ |
| Partially aromatic | (S56+S59+S75) $_{RIC}$ |
| **Diterpenoids** | |
| Major/significant | (D10+D35+D53+D54+D55+D60+D63+D64+D70+D75+D80) $_{m/z\ 123}$ + (D25+D29.8+D55.2) $_{m/z\ 257}$ + (D20+D30) $_{m/z\ 259}$ |
| Tetracyclics | (D5+D63+D65+D75) $_{m/z\ 123}$ + (D52+D57) $_{m/z\ 259}$ |
| $M^+$ 274 (dominant *m/z* 259) | (D16+D20+D21+D22a+D22b+D24+D26+D30+D38+D39.8+D40+D41+D42) $_{m/z\ 259}$ |
| Other $M^+$ 274 compounds | (D15+D25.5+D30.5+D55.4) $_{m/z\ 259}$ + (D39.3+D40.5) $_{m/z\ 123}$ |
| Saturated tricyclics | (D10+D29.5+D35+D36+D45+D50+D51+D53+D54+D55+D60+D64+D70+ D71+D76+D80) $_{m/z\ 123}$ |
| Pimarane | (D55) $_{m/z\ 123}$ |
| **Terrigenous Triterpenoids** | |
| Intact | (H9+H28+H28.2+H33+H36+H53) $_{m/z\ 218}$ + (H37) $_{m/z\ 189}$ + (H57) $_{m/z\ 243}$ |
| Olean-12-ene | (H36) $_{m/z\ 218}$ |
| A-ring contracted | (H8.5+H11a+H16.8+H56) $_{m/z\ 189}$ + (H15+H16+H16.2+H17.2+H17.4+H24+H31) $_{m/z\ 365}$ |
| Des-A triterpenoids | (A20+A25+A32+A34+A35+A36+A38+A40a+A40X+A44+A45+A50a+ A60a+A60X+A65+A70+A72+A80+A95) $_{RIC}$ |
| **Hopanoids** | |
| Hop-17(21)-ene | (H45) $_{m/z\ 191}$ |
| 22R-17α(H),21ß(H)-homohopane | (H80) $_{m/z\ 191}$ |
| **Steroids** | (I2+I4+I10+I20+I40+I45+I50) $_{m/z\ 257}$ |

The sample set used for biomarker evaluation consists of 16 Lochiel samples and 11 Bowmans samples (Table D3.2). In some sub-facies only single samples were available. Caution is required in evaluating abundance variations, especially between the sub-facies.

Table D3.2 Data set available for RCI estimation

| Deposit/ Facies | Sub-Facies | Facies | Deposit |
|---|---|---|---|
| **Lochiel Deposit** | | | |
| *Sub-facies Ic* | 1 | } | } |
| *Sub-facies Ib* | 3 | } 7 | } |
| *Sub-facies Ia* | 3 | } | } |
| Facies II | | 4 | } 16 |
| Facies III | | 3 | } |
| *Sub-facies IVa* | 1 | } | } |
| *Sub-facies IVb* | 1 | } 2 | } |
| **Bowmans Deposit** | | | |
| *Sub-facies Ic* | 1 | } | } |
| *Sub-facies Ib* | 6 | } 8 | } |
| *Sub-facies Ia* | 1 | } | } 11 |
| *Sub-facies IIa-2* | 1 | | } |
| *Sub-facies IIa_3* | 2 | | } |

Appendix D3.2: GC-MS normal alkane peak measurement and RCI estimation (sheet 1 of 2)

| Coal Sample | | | GC-MS Sample | | GC-MS Response Full Scale | | GC-MS Peak Measurement | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | *m/z* 99 (counts) | *m/z* 99 (mm) | $n$-$C_{21}$ *m/z* 99 (mm) | $n$-$C_{22}$ *m/z* 99 (mm) | $n$-$C_{23}$ *m/z* 99 (mm) | $n$-$C_{24}$ *m/z* 99 (mm) | $n$-$C_{25}$ *m/z* 99 (mm) | $n$-$C_{26}$ *m/z* 99 (mm) | $n$-$C_{27}$ *m/z* 99 (mm) | $n$-$C_{28}$ *m/z* 99 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 97140 | 69 | 0.75 | 1 | 14.5 | 6.5 | 42 | 8.5 | 39 | 9 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 95430 | 69 | 1 | 2 | 22.5 | 7 | 52 | 7.5 | 44.5 | 7.5 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 81240 | 69 | 5 | 9 | 35 | 12 | 68 | 7 | 45 | 4 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 535800 | 69 | 0.5 | 1 | 25.5 | 6 | 69 | 5 | 34.5 | 3 |
| V714-51 | Ib | F1 | 1993 | GS-4A | 19890 | 69 | 2 | 2.5 | 16.5 | 5 | 68 | 3 | 35 | 2 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 161400 | 69 | 1 | 1.5 | 19 | 7 | 69 | 6 | 40 | 5 |
| L502 | Ia | G6 | 1994 | GMS-32 | 353100 | 69 | 0.75 | 1.25 | 20 | 7.5 | 68.5 | 4.5 | 25.5 | 2.5 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 101200 | 69 | 1.5 | 1.5 | 21 | 9 | 69 | 9 | 53 | 8 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 33040 | 69 | 2 | 3.5 | 14 | 6 | 34 | 3 | 33 | 3 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 238200 | 69 | 0.5 | 1 | 23 | 9 | 69 | 8 | 51 | 4.5 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 256600 | 69 | 0.5 | 0.5 | 18 | 4.5 | 68 | 3.5 | 39 | 1 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 966400 | 69 | 0.75 | 1 | 13.5 | 5 | 68 | 6 | 45 | 3 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 821600 | 69 | 1.75 | 0.5 | 13 | 5.5 | 68 | 8 | 47 | 6.5 |
| V704-42 | III | G1 | 1993 | GS-9 | 244300 | 69 | 0.5 | 1 | 5 | 4.5 | 50 | 7 | 50 | 5.5 |
| V704-42 | III | G1 | 1994 | GMS-39 | 331100 | 69 | 0.5 | 0.75 | 4.5 | 3.5 | 68 | 5 | 52 | 2 |
| L535 | III | G1 | 1993 | GS-5 | 178000 | 69 | 3.5 | 3 | 24 | 9 | 54 | 12 | 56 | 17 |
| L535 | III | G1 | 1994 | GMS-35 | 306000 | 69 | 3.5 | 2.5 | 19 | 7 | 69 | 7.5 | 55 | 7 |
| L543 | III | F5 | 1993 | GS-1A | 69550 | 69 | 1 | 2 | 12 | 7 | 44 | 9 | 42 | 10 |
| L543 | III | F5 | 1994 | GMS-37 | 168200 | 69 | 3 | 4.5 | 18 | 9 | 68 | 9 | 55 | 7 |
| L155 | IVa | F4 | 1994 | GMS-21 | 183700 | 69 | 10 | 7 | 15 | 8.5 | 68 | 7 | 42 | 4 |
| L388 | IVb | FX | 1993 | GS-6 | 190600 | 69 | 5 | 8 | 24 | 18 | 61 | 18.5 | 68.5 | 10 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 105400 | 69 | 2 | 3.5 | 35.5 | 9 | 64 | 9 | 62 | 7 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 85300 | 69 | 2 | 2 | 23 | 5 | 59 | 6 | 46 | 6.5 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 397500 | 69 | 5 | 3.5 | 33 | 8 | 69 | 7.5 | 52 | 4.5 |
| B28-57 | Ib | C | 1994 | GMS-31 | 214000 | 69 | 2.5 | 2 | 19 | 7 | 58 | 11 | 68 | 5 |
| B28-60 | Ib | C | 1994 | GMS-30 | 343600 | 69 | 0.8 | 0.5 | 5 | 3.5 | 69 | 6.5 | 60 | 2 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 246600 | 69 | 2.5 | 4 | 23.5 | 9 | 68 | 10 | 47 | 5 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 296600 | 69 | 4 | 5 | 16.5 | 7.5 | 69 | 6 | 39 | 2 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 733300 | 69 | 1 | 2 | 15.5 | 8 | 69 | 8 | 44 | 3 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 152000 | 69 | 3 | 5.5 | 25 | 12 | 49 | 10 | 54 | 6 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 949500 | 69 | 2 | 2.5 | 19 | 8 | 68.5 | 7 | 43 | 2 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 466200 | 69 | 1.5 | 4 | 19 | 12 | 67 | 16 | 68 | 10 |

Appendix D3.2: GC-MS normal alkane peak measurement and RCI estimation (sheet 2 of 2)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | CPI | Max | RCI ($n$-$C_{21}$ to $n$-$C_{33}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | $n$-$C_{29}$ *m/z* 99 (mm) | $n$-$C_{30}$ *m/z* 99 (mm) | $n$-$C_{31}$ *m/z* 99 (mm) | $n$-$C_{32}$ *m/z* 99 (mm) | $n$-$C_{33}$ *m/z* 99 (mm) | | $n$-$C^*$ | Response (counts) | RCI (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 69 | 6 | 60 | 1.5 | 10 | 7.1 | 29 | 376945 | 65 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 68.5 | 5 | 56.5 | 1.5 | 7 | 8.3 | 29 | 390710 | 44 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 40 | 1 | 19 | 0 | 1.5 | 7.9 | 25 | 290227 | 18 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 28 | 1.2 | 10 | 0.5 | 1 | 9.9 | 25 | 1438118 | |
| V714-51 | Ib | F1 | 1993 | GS-4A | 51 | 1 | 23 | 0 | 1.5 | 16.9 | 25 | 60679 | 1 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 38 | 5 | 32 | 1.5 | 5.5 | 7.8 | 25 | 539170 | 32 |
| L502 | Ia | G6 | 1994 | GMS-32 | 23 | 1 | 8.5 | 0.5 | 0.75 | 8.5 | 25 | 840532 | 13 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 64 | 8 | 53 | 2 | 6 | 7.0 | 25 | 447333 | 100 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 59 | 2 | 68 | 0.5 | 5 | 14.0 | 31 | 111570 | 3 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 39 | 3.5 | 35 | 1 | 7.5 | 8.0 | 25 | 869948 | 49 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 13 | 0.25 | 4.5 | 0 | 0 | 14.4 | 25 | 568053 | 31 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 23 | 1 | 13.5 | 0.5 | 2 | 10.1 | 25 | 2552557 | 42 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 35 | 3.5 | 20 | 1.5 | 3 | 7.1 | 25 | 2539220 | 36 |
| V704-42 | III | G1 | 1993 | GS-9 | 68.5 | 4.5 | 48 | 1 | 3.5 | 9.8 | 29 | 881604 | 45 |
| V704-42 | III | G1 | 1994 | GMS-39 | 43 | 1.5 | 14 | 0 | 0.5 | 15.0 | 25 | 936917 | 25 |
| L535 | III | G1 | 1993 | GS-5 | 69 | 14.5 | 57 | 6 | 14 | 4.4 | 29 | 874522 | 40 |
| L535 | III | G1 | 1994 | GMS-35 | 38 | 3.2 | 17.5 | 1 | 2.5 | 7.4 | 25 | 1031974 | 46 |
| L543 | III | F5 | 1993 | GS-1A | 68 | 6 | 61 | 2 | 11 | 6.7 | 29 | 277192 | 4 |
| L543 | III | F5 | 1994 | GMS-37 | 50 | 3 | 23 | 1 | 3 | 7.1 | 25 | 617952 | 9 |
| L155 | IVa | F4 | 1994 | GMS-21 | 40 | 2 | 30 | 0.5 | 3.5 | 8.6 | 25 | 632301 | 3 |
| L388 | IVb | FX | 1993 | GS-6 | 55 | 4 | 20 | 1 | 3 | 4.2 | 27 | *n/a* | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 69 | 2 | 20 | 0 | 1 | 8.6 | 29 | 433820 | 6 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 69 | 3 | 31.5 | 0.75 | 5 | 10.3 | 29 | 319875 | 26 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 42 | 1 | 10 | 0.5 | 0.75 | 8.8 | 25 | 1363886 | 19 |
| B28-57 | Ib | C | 1994 | GMS-31 | 39 | 1.5 | 11 | 0 | 1 | 7.6 | 27 | 697826 | 11 |
| B28-60 | Ib | C | 1994 | GMS-30 | 22.5 | 1 | 7 | 0.5 | 1 | 12.0 | 25 | 892862 | 22 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 43 | 2 | 13 | 0 | 1 | 7.0 | 25 | 814852 | 12 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 19 | 0.5 | 3 | 0 | 0 | 8.6 | 25 | 737201 | 14 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 22 | 1 | 4.75 | 0 | 0 | 7.4 | 25 | 1894358 | 16 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 68 | 3 | 21 | 0.5 | 1 | 6.5 | 29 | 568348 | 10 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 7.5 | 0.5 | 2.5 | 0 | 0 | 7.5 | 25 | 2236141 | 28 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 28 | 3 | 9 | 0.75 | 0.75 | 4.4 | 27 | 1614809 | 22 |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 1 of 8)

| Coal Sample | | | GC-MS Sample | | GC-MS Full Scale Response Counts | | | | | GC-MS Plot Scale | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | *m/z* 123 (counts) | *m/z* 204 (counts) | *m/z* 206 (counts) | *m/z* 208 (counts) | RIC (counts) | *m/z* 123 (mm) | *m/z* 204 (mm) | *m/z* 206 (mm) | *m/z* 208 (mm) | RIC (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 509 | 2992 | 2495 | 471 | 48600 | 36 | 36 | 36 | 36 | 36 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 823 | 3024 | 3501 | 465 | 70700 | 36 | 36 | 36 | 36 | 36 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 1829 | 6865 | 7280 | 842 | 232500 | 36 | 36 | 36 | 36 | 36 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 10820 | 21750 | 28990 | 3778 | 773500 | 36 | 36 | 36 | 36 | 36 |
| V714-51 | Ib | F1 | 1993 | GS-4A | 377 | 289 | 785 | 471 | 19280 | 36 | 36 | 36 | 36 | 36 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 5318 | 2942 | 7569 | 1137 | 262700 | 36 | 36 | 36 | 36 | 36 |
| L502 | Ia | G6 | 1994 | GMS-32 | 17620 | 1942 | 53790 | 15100 | 837700 | 36 | 36 | 36 | 36 | 36 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 1490 | 2797 | 3395 | 622 | 75130 | 36 | 36 | 36 | 36 | 36 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 345 | 949 | 2112 | 301 | 35450 | 36 | 36 | 36 | 36 | 36 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 1295 | 471 | 1672 | 320 | 101800 | 36 | 36 | 36 | 36 | 36 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 1521 | 873 | 3143 | 590 | 167900 | 36 | 36 | 36 | 36 | 36 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 2791 | 2275 | 11700 | 1779 | 524400 | 36 | 36 | 36 | 36 | 36 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 2294 | 1119 | 7003 | 3638 | 682800 | 36 | 36 | 36 | 36 | 36 |
| V704-42 | III | G1 | 1993 | GS-9 | 572 | 370 | 792 | 276 | 63090 | 36 | 36 | 36 | 36 | 36 |
| V704-42 | III | G1 | 1994 | GMS-39 | 1728 | 540 | 1163 | 597 | 151500 | 36 | 36 | 36 | 36 | 36 |
| L535 | III | G1 | 1993 | GS-5 | 402 | 282 | 697 | 320 | 42250 | 36 | 36 | 36 | 36 | 36 |
| L535 | III | G1 | 1994 | GMS-35 | 892 | 433 | 1156 | 660 | 81540 | 36 | 36 | 36 | 36 | 36 |
| L543 | III | F5 | 1993 | GS-1A | 289 | 389 | 647 | 345 | 41190 | 36 | 36 | 36 | 36 | 36 |
| L543 | III | F5 | 1994 | GMS-37 | 1081 | 1917 | 3099 | 886 | 246800 | 36 | 36 | 36 | 36 | 36 |
| L155 | IVa | F4 | 1994 | GMS-21 | 4268 | 1565 | 6658 | 1703 | *n/a* | 47 | 47 | 47 | 47 | *n/a* |
| L388 | IVb | FX | 1994 | GMS-34 | 1728 | 12870 | 5199 | 779 | 328300 | 36 | 36 | 36 | 36 | 36 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 104500 | 31160 | 23780 | 27350 | 2664000 | 36 | 36 | 36 | 36 | 36 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 11930 | 2263 | 7072 | 590 | 712400 | 36 | 36 | 36 | 36 | 36 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 21390 | 20330 | 30780 | 8550 | 337000 | 36 | 36 | 36 | 36 | 36 |
| B28-57 | Ib | C | 1994 | GMS-31 | 27750 | 19960 | 99510 | 29340 | 1940000 | 36 | 36 | 36 | 36 | 36 |
| B28-60 | Ib | C | 1994 | GMS-30 | 3860 | 8028 | 14230 | 1666 | 1351000 | 36 | 36 | 36 | 36 | 36 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 22450 | 14110 | 21750 | 6393 | 1003000 | 36 | 36 | 36 | 36 | 36 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 9960 | 5907 | 6538 | 9223 | 428000 | 36 | 36 | 36 | 36 | 36 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 10100 | 5017 | 13620 | 4470 | n/a | 47 | 47 | 47 | 47 | n/a |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 2728 | 1383 | 3847 | 1012 | 411600 | 36 | 36 | 36 | 36 | 36 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 12830 | 12250 | 33660 | 2628 | 2379000 | 36 | 36 | 36 | 36 | 36 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 17470 | 25470 | 22670 | 4639 | 2198000 | 36 | 36 | 36 | 36 | 36 |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 2 of 8)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | S5 RIC (mm) | S9 *m/z* 123 (mm) | S10 *m/z* 123 (mm) | S10.5 *m/z* 206 (mm) | S11 *m/z* 204 (mm) | S12 *m/z* 123 (mm) | S13 *m/z* 204 (mm) | S13 RIC (mm) | S13.5 *m/z* 204 (mm) | S14 *m/z* 206 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | 35 | 30 | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | 32 | 24 | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | 28 | 16 | | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | | | 3.5 | | 35 | 16 | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | 12 | | | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | | | | 10 | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | | | | | | | 18 | 3.5 | | 2.5 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | | | 8 | 0.5 | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | 16 | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | 20 | 12 | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | 30 | 10 | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | 18 | 4 | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | 25 | 3 | | |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | 30 | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | 10 | 1 | | |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | 15 | 1 | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | | | |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | | | 3.5 | | 27 | 5 | 3 | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | 35 | | 28 | 32 | 1 | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 1 | 2.5 | 2.5 | | | 27 | 35 | 4 | | |
| B28-57 | Ib | C | 1994 | GMS-31 | | | | | | | 18 | 2.5 | 4 | |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | 34 | 4 | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | | 7 | 3 | | 70 | 15 | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | | | 13 | | 140 | 28 | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | | 11 | | | 24 | | 17 | 15 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | 16 | | | | | 16 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | | | | 12 | 32 | 2 | | 9 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | | | | 16 | 15 | 3 | | 16 |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 3 of 8)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Unique ID** | **Facies** | **Ply** | **Run** | **File ID** | S14.5 ***m/z* 204** (mm) | S15 ***m/z* 123** (mm) | S20 ***m/z* 206** (mm) | S21 ***m/z* 123** (mm) | S25 ***m/z* 208** (mm) | S31 ***m/z* 204** (mm) | S32 ***m/z* 123** (mm) | S33 ***m/z* 208** (mm) | S34 ***m/z* 123** (mm) | S34 **RIC** (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | 6 | | | 15 | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | 7 | | | 8 | | | | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | 32 | 4 | | 33 | | | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | 5 | 5 | 32 | 25 | 32 | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | | | | | 6 | 25 | | | | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | 10 | | | | | | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | 12 | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | 14 | | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | | 12 | 11.5 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | 25 | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | | | 8 | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | 20 | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | 30 | 20 |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | | | |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | 8 | | | 4.5 | | | | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | 3 | | | | | | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | 4 | 10 | | 36 | | | 12 | | |
| B28-57 | Ib | C | 1994 | GMS-31 | 7 | | | | 3.5 | 35 | | | | |
| B28-60 | Ib | C | 1994 | GMS-30 | | | 9 | | | | | | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | 7 | | 10 | 12 | | | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | 8 | 32 | | 8 | 11 | | | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | 10 | 20 | | 18 | 40 | 11 | 10 | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | 33 | | 25 | 30 | | | | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | 4 | | | 22 | | | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 8 | | 9 | | 23 | 32 | | | | |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 4 of 8)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | S34.5 *m/z* 206 (mm) | S35 *m/z* 123 (mm) | S35 RIC (mm) | S36 *m/z* 208 (mm) | S36.5 *m/z* 208 (mm) | S37 *m/z* 123 (mm) | S39.8 *m/z* 204 (mm) | S40 *m/z* 123 (mm) | S40 RIC (mm) | S40.5 *m/z* 206 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | 20 | 15 | 20 | 5 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | 36 | 28 | 28 | 7 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | 34 | 15 | *n/a* | 8 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | 1 | 0.2 | 22 | | | 27 | 32 | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | 10 | 12 | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | | | | | | 20 | 32 | |
| L502 | Ia | G6 | 1994 | GMS-32 | 7.5 | | | | | 33 | | | | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | | | 32 | 10 | 28 | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | 15 | 30 | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | 30 | 32 | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | 30 | 32 | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | 30 | 10 | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | | 3 | |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | 20 | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | 8 | 13 | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | 15 | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | 30 | | | |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | 72 | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | 140 | 34 | | | 35 | 7 | | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | | | | 9 | 21 | 35 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | 5 | 0.1 | 12 | | | 144 | 72 | |
| B28-57 | Ib | C | 1994 | GMS-31 | 4 | 34 | 3.5 | | | | | 32 | 21 | |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | | 30 | 6.5 | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | 70 | 10 | | | | 13 | 32 | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | 140 | 22 | 8 | | | 13 | 30 | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | 43 | | 18 | 20 | | | | 45 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | 30 | 1 | | | | | | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | 17 | 0.2 | 15 | | | 67 | 34 | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | 13 | 0.5 | | | | 38 | 25 | |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 5 of 8)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | S40.7 *m/z* 206 (mm) | S41.5 *m/z* 123 (mm) | S43 *m/z* 123 (mm) | S43.5 *m/z* 206 (mm) | S44 *m/z* 206 (mm) | S45 *m/z* 123 (mm) | S47 *m/z* 206 (mm) | S50 *m/z* 123 (mm) | S52 *m/z* 204 (mm) | S54 *m/z* 208 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | | | | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | | | | | | | | 6 |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | 7 | | | | | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | | | | 3 | 3.5 | | 5.5 | 10 | | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | | | | | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | | 5 | | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | | | |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | | | | 2 | | | 4.5 | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | | | | | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | 6 | | | 13 | | | | |
| B28-57 | Ib | C | 1994 | GMS-31 | | | | | 3 | | 6 | 8 | | |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | | | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | | | | | | | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | | | | | | | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | 5 | | | | 32 | | | | 42 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | | | | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | | | | | | | 15 | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | | | | 7 | | | 22 | 22 |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 6 of 8)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | S55 *m/z* 206 (mm) | S56 RIC (mm) | S56.5 *m/z* 206 (mm) | S56.5 RIC (mm) | S57 *m/z* 123 (mm) | S58 *m/z* 204 (mm) | S59 RIC (mm) | S60 *m/z* 206 (mm) | S60 RIC (mm) | S66 *m/z* 206 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | 7 | 12 | | | 7 | 30 | 16 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | 5 | 12 | | | 6 | 35 | 15 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | | 6 | 35 | 14 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | 8 | 3 | | | | | | 35 | 13 |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | | 25 | 10 |
| V714-72 | Ia | H1 | 1993 | GS-11 | | 33 | | | | | | 10 | 6 | 1.5 |
| L502 | Ia | G6 | 1994 | GMS-32 | | 35 | | | | | | 1.5 | 5 | 5 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | 5 | 8 | | | 6 | 34 | 15 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | 32 | 15 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | 2.5 | 30 | 7 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | | 32 | 8 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | | 70 | 15 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | | 32 | 3 |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | | 10 | 11 |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | 30 | 5 |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | 20 | 6 |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | | 25 | 5 |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | 25 | 5 |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | 3 | 35 | 5 |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | | 43 | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | 11 | 22 | 3 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | | | | | | 4 | 70 | 8 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | | | | | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | | | | 15 | 4 | | | |
| B28-57 | Ib | C | 1994 | GMS-31 | | 34 | | | | | | 5 | 8 | 5 |
| B28-60 | Ib | C | 1994 | GMS-30 | | 6.5 | | | | | | 0.5 | 34 | 4 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | | | | | | | 34 | 7 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | 12 | | | | | | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | 13 | | | | 12 | | | 5 | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | | | 21 | 4 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | | | | | | | 31 | 4 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | | | | | | 18 | 13 | 1 |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 7 of 8)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | Relative Concentration Index Major Sesquiterpenoids | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | S67 *m/z* 208 (mm) | S70a *m/z* 123 (mm) | S70b *m/z* 204 (mm) | S72 *m/z* 208 (mm) | S73 *m/z* 204 (mm) | S75 RIC (mm) | Response (counts) | RCI | RCI (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | 6862 | 96 | 36 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | 10 | 11599 | 107 | 41 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | 22604 | 111 | 42 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | | | | | 77298 | *n/a* | *n/a* |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | 755 | 1 | 0 |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | | | | | 17081 | 83 | 32 |
| L502 | Ia | G6 | 1994 | GMS-32 | 35 | | 9 | | 11 | | 64927 | 79 | 30 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | | | 8603 | 156 | 60 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | 2812 | 6 | 2 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | 3 | 3265 | 15 | 6 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | 5890 | 26 | 10 |
| V704-31 | IIa | G5 | 1994 | GMS-22 | | | | | | | 28552 | 38 | 15 |
| V714-50 | IIa | F2 | 1994 | GMS-20S | | | | | | | 6225 | 7 | 3 |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | 817 | 3 | 1 |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | 2224 | 5 | 2 |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | 387 | 1 | 1 |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | 803 | 3 | 1 |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | 611 | 1 | 0 |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | 4610 | 5 | 2 |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | 6091 | 2 | 1 |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | 28917 | *n/a* | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | | | | | 538103 | 639 | 244 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | 15 | | 18942 | 126 | 48 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | 6 | | | | 143912 | 160 | 61 |
| B28-57 | Ib | C | 1994 | GMS-31 | 36 | | | | | | 199208 | 262 | 100 |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | 31437 | 62 | 24 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | | | | | 116624 | 138 | 52 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | | | | | 78989 | 118 | 45 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | 18 | | | | 31160 | 21 | 8 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | 11609 | 17 | 6 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | | | | | 85120 | 88 | 34 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | | | | 1 | 86139 | 96 | 37 |

Appendix D3.3: GC-MS sesquiterpenoid peak measurement and RCI estimation (sheet 8 of 8)

| Coal Sample | | | GC-MS Sample | | Relative Concentration Index | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sat. Sesquiterpenoids | | Unsat. Sesquiterpenoids | | Diunsat. Sesquiterpenoids | | Arom. Sesquiterpenoids | |
| Unique ID | Facies | Ply | Run | File ID | Response (counts) | RCI (norm.) | Response (counts) | RCI (norm.) | Response (counts) | RCI (norm.) | Response (counts) | RCI (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 0 | 0 | 3123 | 18 | 4571 | 84 | 9450 | 37 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 0 | 0 | 5794 | 22 | 6972 | 85 | 31422 | 82 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 0 | 0 | 10873 | 22 | 13349 | 87 | 38750 | 54 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 6702 | | 61218 | | 21146 | | 64458 | *n/a* |
| V714-51 | Ib | F1 | 1993 | GS-4A | 0 | 0 | 650 | 0 | 0 | 0 | 0 | 0 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 5517 | 35 | 14941 | 30 | 4086 | 26 | 72972 | 100 |
| L502 | Ia | G6 | 1994 | GMS-32 | 26216 | 42 | 109949 | 55 | 2643 | 4 | 34904 | 12 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 0 | 0 | 5601 | 42 | 4040 | 96 | 12522 | 64 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 0 | 0 | 2021 | 2 | 791 | 2 | 0 | 0 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 0 | 0 | 3030 | 6 | 236 | 1 | 15553 | 20 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 0 | 0 | 5791 | 10 | 606 | 4 | 0 | 0 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 0 | 0 | 26051 | 14 | 3476 | 6 | 0 | 0 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 0 | 0 | 6808 | 3 | 0 | 0 | 0 | 0 |
| V704-42 | III | G1 | 1993 | GS-9 | 0 | 0 | 824 | 1 | 103 | 1 | 0 | 0 |
| V704-42 | III | G1 | 1994 | GMS-39 | 0 | 0 | 3439 | 3 | 225 | 1 | 0 | 0 |
| L535 | III | G1 | 1993 | GS-5 | 0 | 0 | 387 | 1 | 0 | 0 | 0 | 0 |
| L535 | III | G1 | 1994 | GMS-35 | 0 | 0 | 803 | 1 | 0 | 0 | 0 | 0 |
| L543 | III | F5 | 1993 | GS-1A | 0 | 0 | 449 | 0 | 162 | 0 | 0 | 0 |
| L543 | III | F5 | 1994 | GMS-37 | 0 | 0 | 3702 | 2 | 1598 | 2 | 20567 | 7 |
| L155 | IVa | F4 | 1994 | GMS-21 | 0 | 0 | 8500 | 1 | 0 | 0 | *n/a* | *n/a* |
| L388 | IVb | FX | 1994 | GMS-34 | 0 | | 8232 | | 25740 | | 100314 | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 412194 | 637 | 76797 | 37 | 64051 | 100 | 296000 | 99 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 11599 | 100 | 10447 | 28 | 4715 | 41 | 0 | 0 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 38908 | 56 | 97972 | 45 | 40660 | 60 | 0 | 0 |
| B28-57 | Ib | C | 1994 | GMS-31 | 58401 | 100 | 185627 | 100 | 35484 | 61 | 269444 | 100 |
| B28-60 | Ib | C | 1994 | GMS-30 | 0 | 0 | 25945 | 21 | 7582 | 20 | 18764 | 10 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 49794 | 76 | 40128 | 19 | 32139 | 50 | 0 | 0 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 42832 | 83 | 13983 | 9 | 24777 | 49 | 142667 | 60 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 31331 | 28 | 30548 | 9 | 10568 | 9 | *n/a* | *n/a* |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 2976 | 6 | 9831 | 6 | 1153 | 2 | 0 | 0 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 7154 | 10 | 71563 | 30 | 27563 | 37 | 0 | 0 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 15504 | 23 | 46148 | 21 | 65798 | 97 | 1160056 | 365 |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 1 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Full Scale Response Counts | | | | GC-MS Plot Scale | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | *m/z* 123 (counts) | *m/z* 257 (counts) | *m/z* 259 (counts) | RIC (counts) | *m/z* 123 (mm) | *m/z* 257 (mm) | *m/z* 259 (mm) | RIC (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 1389 | 3904 | 836 | 96630 | 46 | 46 | 46 | 46 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 1263 | 1565 | 1005 | 764400 | 46 | 46 | 46 | 46 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 3193 | 3099 | 2426 | 228600 | 46 | 46 | 46 | 46 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 88880 | 25090 | 22000 | 1660000 | 46 | 46 | 46 | 46 |
| V714-51 | Ib | F1 | 1993 | GS-4A | 12500 | 2697 | 19650 | 311300 | 46 | 46 | 46 | 46 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 71460 | 60130 | 21030 | 1370000 | 46 | 46 | 46 | 46 |
| L502 | Ia | G6 | 1994 | GMS-32 | 32230 | 29060 | 23990 | 1073000 | 46 | 46 | 46 | 46 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 19450 | 23220 | 14590 | 775500 | 46 | 46 | 46 | 46 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 679 | 804 | 370 | 47640 | 46 | 46 | 46 | 46 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 1716 | 1075 | 1282 | 174800 | 46 | 46 | 46 | 46 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 3439 | 1301 | 2250 | 164900 | 46 | 46 | 46 | 46 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 14890 | 6129 | 8380 | 1497000 | 46 | 46 | 46 | 46 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 23900 | 9883 | 17840 | 605200 | 46 | 46 | 46 | 46 |
| V704-42 | III | G1 | 1993 | GS-9 | 1100 | 1188 | 697 | 217600 | 46 | 46 | 46 | 46 |
| V704-42 | III | G1 | 1994 | GMS-39 | 3929 | 2527 | 1716 | 412200 | 46 | 46 | 46 | 46 |
| L535 | III | G1 | 1993 | GS-5 | 3822 | 1540 | 609 | 683000 | 46 | 46 | 46 | 46 |
| L535 | III | G1 | 1994 | GMS-35 | 7796 | 2848 | 1150 | 346700 | 46 | 46 | 46 | 46 |
| L543 | III | F5 | 1993 | GS-1A | 1282 | 1181 | 565 | 127300 | 46 | 46 | 46 | 46 |
| L543 | III | F5 | 1994 | GMS-37 | 9141 | 3948 | 2288 | 357900 | 46 | 46 | 46 | 46 |
| L155 | IVa | F4 | 1994 | GMS-21 | 14490 | 4338 | 4985 | *n/a* | 64 | 64 | 64 | *n/a* |
| L388 | IVb | FX | 1994 | GMS-34 | 2885 | 1383 | 936 | 400300 | 46 | 46 | 46 | 46 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 15100 | 43780 | 10410 | 606700 | 46 | 46 | 46 | 46 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 33090 | 35890 | 7022 | 1470000 | 46 | 46 | 46 | 46 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 2200000 | 3076000 | 995900 | 22560000 | 46 | 46 | 46 | 46 |
| B28-57 | Ib | C | 1994 | GMS-31 | 98610 | 144800 | 71550 | 2144000 | 46 | 46 | 46 | 46 |
| B28-60 | Ib | C | 1994 | GMS-30 | 121600 | 12410 | 21450 | 2253000 | 46 | 46 | 46 | 46 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 633400 | 36420 | 152500 | 9933000 | 46 | 46 | 46 | 46 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 15030 | 50370 | 17850 | 460300 | 46 | 46 | 46 | 46 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 106100 | 91600 | 63150 | *n/a* | 64 | 64 | 64 | *n/a* |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 4602 | 34050 | 4382 | 1016000 | 46 | 46 | 46 | 46 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 114200 | 101500 | 23000 | 2155000 | 46 | 46 | 46 | 46 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 100800 | 290100 | 29730 | 3054000 | 46 | 46 | 46 | 46 |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 2 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | D5 *m/z* 123 (mm) | D8 RIC (mm) | D10 *m/z* 123 (mm) | D15X RIC (mm) | D15 *m/z* 259 (mm) | D16 *m/z* 259 (mm) | D20 *m/z* 259 (mm) | D21 *m/z* 259 (mm) | D22a *m/z* 259 (mm) | D22b *m/z* 259 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | 22 | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | 30 | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | 7 | | | 1.5 | 3 | 27 | | 2 | 3 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | | | | | 45 | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | 2 | | | | 22 | | 17 | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | 5 | | | 1 | 5.5 | 31 | | | 6 |
| L502 | Ia | G6 | 1994 | GMS-32 | | | 4 | | | | 26 | | | 15 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | 20 | | | | | | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | 40 | | | 15 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | 42 | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | 1.5 | | 45 | | | 10 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | 6 | | | 1 | | 43 | | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | 25 | | | 20 |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | 40 | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | 30 | | | 30 |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | 35 | | | 28 |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | 55 | | | 41 |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | 34 | | 35 | 37 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | 21 | 4.5 | | 41 | 25 | 17 | | 11 | 14 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | 4 | 7 | 10 | | | | 18 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | 6.5 | 11 | | | 9 | 5.5 | | 38 |
| B28-57 | Ib | C | 1994 | GMS-31 | | | 6 | | | | 20 | | 45 | 14 |
| B28-60 | Ib | C | 1994 | GMS-30 | | | 1.5 | | 2 | 15 | 45 | | 12 | 8 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | | | 4 | 9 | 33 | | 7 | 39 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | 11 | | 33 | 45 | 23 | | 35 | 20 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | | 5 | | 16 | 62 | | 24 | 17 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | 1 | | | 10 | 20.5 | 45 | | 22 | 15 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | | 0.5 | 5 | 11 | 22 | | 16 | 23 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | 2 | | 3 | 15 | 25 | | 32 | |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 3 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | D24 *m/z* 259 (mm) | D25 *m/z* 257 (mm) | D25.5 *m/z* 259 (mm) | D25.5 RIC (mm) | D26 *m/z* 259 (mm) | D28 *m/z* 123 (mm) | D28.2 *m/z* 257 (mm) | D28.4 *m/z* 257 (mm) | D29 RIC (mm) | D29.4 RIC (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | | | | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 10 | 15 | | | | | | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | 10 | | | | | 5 | 5 | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | 7 | | | | | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | 14 | 23 | | | | | 2.5 | | | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | 6 | | | | | 5 | 7 | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | 10 | | | | | | | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 23 | 7 | | | | | | 10 | | |
| V704-42 | III | G1 | 1993 | GS-9 | | 7 | | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | 26 | 11 | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | 15 | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | 13 | | | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | 6 | | | | | | | | |
| L155 | IVa | F4 | 1994 | GMS-21 | | 11 | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | 6 | | | | | | | | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | 10 | | | | | 1 | 2 | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 3 | 21 | 1 | 2.5 | | 2 | 3.5 | 3.5 | | |
| B28-57 | Ib | C | 1994 | GMS-31 | | 8 | | | | | 6.5 | 6.25 | 7.5 | 0.75 |
| B28-60 | Ib | C | 1994 | GMS-30 | 6 | 13 | | | 9 | | 3 | 3 | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | 10 | | | 17 | | 5 | 8 | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 7 | 19 | | | | | 4 | 4.5 | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 13 | 12 | | | | | 5.5 | 7 | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | 7 | | | | | 4 | 5 | | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | 8 | | | | | 2.5 | 2 | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 22 | 10 | | | | | 3 | 2 | | |
| | | | | | | | | | | | 3.5 | | | |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 4 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | D29.5 *m/z* 123 (mm) | D29.8 *m/z* 257 (mm) | D30 *m/z* 259 (mm) | D30.5 *m/z* 259 (mm) | D31 RIC (mm) | D32 *m/z* 257 (mm) | D35 *m/z* 123 (mm) | D36 *m/z* 123 (mm) | D38 *m/z* 259 (mm) | D38.5 *m/z* 257 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | 43 | 15 | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | 25 | 35 | | | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | 35 | 40 | | | | | 10 | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | 45 | 45 | | 6 | 4 | | 23 | 7 |
| V714-51 | Ib | F1 | 1993 | GS-4A | | 8 | 42 | 40 | | | 12 | 4 | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | 14 | 31 | | 3.5 | 2 | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | | | 45 | 33 | | 8 | 9.5 | | 19 | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | 16 | 45 | | 11 | | | | 2.5 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | 35 | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | 38 | 35 | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | 40 | 35 | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | 44 | 26 | | | | | 17 | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | 40 | 17 | | | 16 | | 11 | |
| V704-42 | III | G1 | 1993 | GS-9 | | | 35 | 30 | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | 41 | 25 | | | | | 20 | |
| L535 | III | G1 | 1993 | GS-5 | | | 40 | 20 | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | 40 | 20 | | | 4 | | 26 | |
| L543 | III | F5 | 1993 | GS-1A | | | 10 | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | 20 | 20 | | | | | | |
| L155 | IVa | F4 | 1994 | GMS-21 | | | 55 | 22 | | | | | 15 | |
| L388 | IVb | FX | 1994 | GMS-34 | | | 35 | 35 | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | 46 | 45 | | 3.5 | 15 | | 40 | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | 46 | 22 | | 6 | | | | 4.5 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | 27.5 | 3 | 2 | 4.5 | | | 15.5 | 10 |
| B28-57 | Ib | C | 1994 | GMS-31 | | | 45 | 22 | | 3 | 13 | | 15 | |
| B28-60 | Ib | C | 1994 | GMS-30 | | | 45 | 41 | | | 37.5 | | 21 | 23 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | 45 | 45 | | 5 | 3.5 | | 23 | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | 27 | 22 | | 5 | | | 20 | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | 57 | 48 | 9 | 8 | | | 25 | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | 46 | 43 | | 2 | 17 | | 25 | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | 46 | 35 | | 5 | 12 | | 22 | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | 46 | 36 | | 4 | 34 | | 25 | 5 |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 5 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Unique ID** | **Facies** | **Ply** | **Run** | **File ID** | D39 ***m/z* 257** (mm) | D39.3 ***m/z* 123** (mm) | D39.5 ***m/z* 123** (mm) | D39.5 **RIC** (mm) | D39.8 ***m/z* 259** (mm) | D40 ***m/z* 259** (mm) | D40.5 ***m/z* 123** (mm) | D40.5 **RIC** (mm) | D41 ***m/z* 259** (mm) | D42 ***m/z* 259** (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | 36 | | | | | 7 | 0.1 | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | 35 | | | | 20 | | | | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | | | | 20 | | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | 3 | 3 | | | | | 4 | 6 | | |
| L502 | Ia | G6 | 1994 | GMS-32 | 10 | | | | | | | | | |
| V714-66 | Ia | G2 | 1993 | GS-7 | 1.5 | 5.5 | | | | | 4.5 | 6 | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | 15 | | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | 3 | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | | 30 | | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | 26 | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | | | |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | 35 | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 5 | | | | | 42 | | | | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 4 | 1 | | | | | 3 | 4 | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 12.5 | | 5 | 27 | 8 | | | | 6.5 | 5.5 |
| B28-57 | Ib | C | 1994 | GMS-31 | 4 | | | | | 14 | | | | |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | | | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 5 | | | | | 30 | | | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 10.5 | | | | | | | | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | | | | 15 | | | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 4 | | | | | 12 | | | | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 4 | | | | | 28 | | | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | 3 | 5 | | 33 | | | | |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 6 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | D45 *m/z* 123 (mm) | D47 *m/z* 259 (mm) | D48 RIC (mm) | D50 *m/z* 123 (mm) | D51 *m/z* 123 (mm) | D51.5 *m/z* 257 (mm) | D52 *m/z* 259 (mm) | D53 *m/z* 123 (mm) | D54 *m/z* 123 (mm) | D55 *m/z* 123 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | 40 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | | | 12 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | | | | 40 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | 3 | 12 | | | | | | | 46 |
| V714-51 | Ib | F1 | 1993 | GS-4A | | 12 | | | 5 | 9 | | | | 184 |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | 21 | | 1.5 | 1 | 1.5 | | | 46 |
| L502 | Ia | G6 | 1994 | GMS-32 | | | 14 | | 6 | | | | | 83 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | 12 | 4 | | | | | 93 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | | 10 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | | | 25 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | | | 30 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | | | 43 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | 11 | | | | | | | 28 |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | | | 35 |
| V704-42 | III | G1 | 1994 | GMS-39 | | | 25 | | | | | | | 42 |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | 42 |
| L535 | III | G1 | 1994 | GMS-35 | | | 30 | | | | | | | 42 |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | 40 |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | | | 43 |
| L155 | IVa | F4 | 1994 | GMS-21 | | | 22 | | | | | | | 55 |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | | | 40 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | 10 | | | | | | 21 | 43 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | 3 | | | | 76.5 | 103 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | | | 20 | | 3.5 | | | 19 |
| B28-57 | Ib | C | 1994 | GMS-31 | | | | | 1.5 | | 1.5 | | 5 | 20 |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | | | 3 | 46 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | 11 | 2 | | | | | 10 | | 46 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | | | | | | | 16 | 23 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | 12 | | | | | | | 29 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | | | | 14 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | 5 | | | 2 | 4 | | 31 | 13 | 38 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | 7 | 41 | | 4 | 5 | | 12 | 3 | 46 |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 7 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | D55 RIC (mm) | D55.2 *m/z* 257 (mm) | D55.4 *m/z* 259 (mm) | D56 *m/z* 257 (mm) | D57 *m/z* 259 (mm) | D60 *m/z* 123 (mm) | D62 RIC (mm) | D63 *m/z* 123 (mm) | D63 RIC (mm) | D64 *m/z* 123 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 22 | 21 | | | | 22 | 25 | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | 0.5 | 12 | | | | | 2 | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 3 | 40 | | | | | | | | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 45 | 19 | | | | 3 | | 24 | 14 | |
| V714-51 | Ib | F1 | 1993 | GS-4A | 180 | | | | | | | | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | 44 | 46 | | 2.5 | | | | 29 | 17 | |
| L502 | Ia | G6 | 1994 | GMS-32 | 43 | 41 | | 6.5 | | 15 | | 100 | 30 | |
| V714-66 | Ia | G2 | 1993 | GS-7 | 44 | 45 | | 2 | | 17 | | | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | 8 | 25 | | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | 4 | 20 | | | | | 6 | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 11 | 25 | | | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 7 | 35 | | | | | | 9 | 1 | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 21 | 21 | | | | | | 25 | 11 | |
| V704-42 | III | G1 | 1993 | GS-9 | 3 | 36 | | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | 7 | 36 | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | 4 | 30 | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | 19 | 38 | | | | 11 | | 12 | 2.5 | |
| L543 | III | F5 | 1993 | GS-1A | 9 | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | 20 | 43 | | | | 5 | | 20 | 7 | |
| L155 | IVa | F4 | 1994 | GMS-21 | | 45 | | | | | | 25 | | |
| L388 | IVb | FX | 1994 | GMS-34 | 5 | 25 | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 17 | 21 | | | | | | | | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 46 | 18 | | 1.5 | | | | | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 33 | 46.5 | 3 | 6.5 | 10 | 6 | | | | |
| B28-57 | Ib | C | 1994 | GMS-31 | 18 | 17 | | 2.5 | | | | | | 45 |
| B28-60 | Ib | C | 1994 | GMS-30 | 44 | 25 | | | | | | | | 26 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 45 | 26 | 5 | 2.5 | | | | | | 4 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 17 | 45 | | 6 | | | | | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | 62 | | 5 | | | | 9 | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 2.5 | 14 | | | | | | 40 | 3.5 | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 42 | 20 | | | | | | 10 | | 40 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 21 | 35 | | 1.5 | | | | 22 | | 43 |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 8 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | D64 RIC (mm) | D65 *m/z* 123 (mm) | D70 *m/z* 123 (mm) | D70 RIC (mm) | D70.5 RIC (mm) | D71 *m/z* 123 (mm) | D72 *m/z* 123 (mm) | D75 *m/z* 123 (mm) | D75 RIC (mm) | D76 *m/z* 123 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | 32 | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | 35 | 10 | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | 35 | | | | | 3.5 | 2.5 | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | 1 | 2 | 0.75 | | | | 7 | 5 | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | 2.5 | 0.5 | | | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | | 6 | 14 | 3 | | | | 14 | 5 | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | | | | | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | 30 | 4 | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | 42 | 7 | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | 43 | 5 | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | 42 | 16 | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | 12 | 0.25 | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | 9 | 1 | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | 14 | 7 | |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | | | | | 25 | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | | | | | | 44 | 11 | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | 3 | 10 | 1 | | | | | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | 47 | 93 | 43 | | 25 | 2 | 1 | 1.5 | |
| B28-57 | Ib | C | 1994 | GMS-31 | 43 | | 4.5 | 2 | | | | 2 | 2 | |
| B28-60 | Ib | C | 1994 | GMS-30 | 25 | | | | 1 | | | | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 5 | | | | 2 | | | | | 4 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | 14 | 41 | 6 | | | | | | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | 7 | | | | | 63 | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | | 28 | 1 | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | 5 | 1 | | | | 7 | 5 | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | | 8 | 2 | | | | 13 | 6 | |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 9 of 10)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | Relative Concentration Index | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | D80 | D85 | D90 | Major | | | Tetracyclic | | $M^+274$ *m/z* 259 Dominant | |
| ID | Facies | Ply | Run | File ID | *m/z* 123 (mm) | RIC (mm) | RIC (mm) | Response (counts) | RCI | RCI (norm.) | Response (counts) | RCI (norm.) | Response (counts) | RCI (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | 17 | 7576 | 106 | 5 | 0 | 0 | 273 | 1 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | 3712 | 34 | 2 | 879 | 4 | 1245 | 2 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | 16380 | 81 | 4 | 2429 | 5 | 5274 | 5 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | | | 236928 | | | 68592 | | 62174 | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | 94522 | 155 | 8 | 1902 | 1 | 36310 | 12 |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | | 238419 | 1163 | 57 | 45051 | 100 | 32002 | 32 |
| L502 | Ia | G6 | 1994 | GMS-32 | | | | 267241 | 327 | 16 | 87582 | 49 | 53717 | 13 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | 111307 | 2020 | 99 | 0 | 0 | 27277 | 100 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | 1196 | 3 | 0 | 0 | 0 | 0 | 0 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | 5497 | 25 | 1 | 1119 | 2 | 2508 | 2 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | 10987 | 48 | 2 | 3140 | 6 | 3766 | 3 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | 55544 | 74 | 4 | 16832 | 10 | 17853 | 5 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | 95551 | 108 | 5 | 37928 | 20 | 37619 | 9 |
| V704-42 | III | G1 | 1993 | GS-9 | | | | 3685 | 15 | 1 | 0 | 0 | 1136 | 1 |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | 11871 | 25 | 1 | 1025 | 1 | 4141 | 2 |
| L535 | III | G1 | 1993 | GS-5 | | | | 6997 | 26 | 1 | 0 | 0 | 1059 | 1 |
| L535 | III | G1 | 1994 | GMS-35 | | | | 20228 | 73 | 4 | 2034 | 3 | 3375 | 2 |
| L543 | III | F5 | 1993 | GS-1A | | | | 1372 | 1 | 0 | 0 | 0 | 0 | 0 |
| L543 | III | F5 | 1994 | GMS-37 | | | | 23212 | 27 | 1 | 6756 | 4 | 995 | 0 |
| L155 | IVa | F4 | 1994 | GMS-21 | | | | 37294 | 15 | 1 | 11320 | 2 | 10359 | 1 |
| L388 | IVb | FX | 1994 | GMS-34 | | | | 5025 | | | 0 | | 1424 | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | | 127731 | 152 | 7 | 21337 | 12 | 52729 | 13 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 2.5 | | | 204682 | 1360 | 67 | 2158 | 7 | 9770 | 13 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | | 12829800 | 14304 | 704 | 2512152 | 1274 | 1753650 | 395 |
| B28-57 | Ib | C | 1994 | GMS-31 | | 2 | 1 | 477537 | 629 | 31 | 4287 | 3 | 284645 | 76 |
| B28-60 | Ib | C | 1994 | GMS-30 | 6 | 1 | | 375746 | 742 | 37 | 0 | 0 | 69013 | 28 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 25 | | | 1720329 | 2031 | 100 | 33152 | 18 | 540380 | 129 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 10 | | | 148474 | 221 | 11 | 4574 | 3 | 56654 | 17 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | | 458498 | 312 | 15 | 119363 | 37 | 204251 | 28 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | 5.5 | | 70283 | 101 | 5 | 6903 | 5 | 15623 | 5 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | 7 | 2.5 | 523211 | 541 | 27 | 57704 | 27 | 69000 | 14 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | 9 | 7 | 966118 | 1081 | 53 | 84451 | 43 | 126676 | 29 |

Appendix D3.4: GC-MS diterpenoid peak measurement and RCI estimation (sheet 10 of 10)

| Coal Sample | | | GC-MS Sample | | Relative Concentration Index | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Other M+ 274 Diterpenoids | | Tricyclic Diterpenoids | | Pimarane | |
| Unique ID | Facies | Ply | Run | File ID | Response (counts) | RCI (norm.) | Response (counts) | RCI (norm.) | RCI (norm.) | |
| V714-54 | Ic | G6 | 1993 | GS-10 | 0 | 0 | 1872 | 3 | 2 | |
| V714-60 | Ib | G4 | 1993 | GS-8 | 1181 | 14 | 329 | 0 | 0 | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 2429 | 16 | 5206 | 2 | 2 | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 1435 | | 112066 | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | 0 | 0 | 63587 | 10 | 11 | |
| V714-72 | Ia | H1 | 1993 | GS-11 | 10874 | 69 | 85441 | 41 | 47 | |
| L502 | Ia | G6 | 1994 | GMS-32 | 2868 | 5 | 89333 | 11 | 10 | |
| V714-66 | Ia | G2 | 1993 | GS-7 | 4228 | 100 | 56659 | 100 | 95 | |
| V714-56 | IIa | G5 | 1993 | GS-56 | 0 | 0 | 148 | 0 | 0 | |
| V714-63 | IIa | G3 | 1993 | GS-12 | 560 | 3 | 933 | 0 | 1 | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 0 | 0 | 2243 | 1 | 1 | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 0 | 0 | 13919 | 2 | 2 | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 0 | 0 | 22861 | 3 | 2 | |
| V704-42 | III | G1 | 1993 | GS-9 | 717 | 4 | 837 | 0 | 0 | |
| V704-42 | III | G1 | 1994 | GMS-39 | 0 | 0 | 3587 | 1 | 1 | |
| L535 | III | G1 | 1993 | GS-5 | 0 | 0 | 3490 | 1 | 2 | |
| L535 | III | G1 | 1994 | GMS-35 | 0 | 0 | 11186 | 4 | 3 | |
| L543 | III | F5 | 1993 | GS-1A | 0 | 0 | 1115 | 0 | 0 | |
| L543 | III | F5 | 1994 | GMS-37 | 0 | 0 | 9538 | 1 | 1 | |
| L155 | IVa | F4 | 1994 | GMS-21 | 0 | 0 | 12452 | 0 | 1 | |
| L388 | IVb | FX | 1994 | GMS-34 | 0 | *n/a* | 2509 | *n/a* | *n/a* | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 5658 | 9 | 25933 | 3 | 2 | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 4404 | 38 | 143150 | 92 | 66 | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 86600 | 126 | 8321739 | 902 | 136 | |
| B28-57 | Ib | C | 1994 | GMS-31 | 0 | 0 | 190789 | 24 | 8 | |
| B28-60 | Ib | C | 1994 | GMS-30 | 6995 | 18 | 313252 | 60 | 32 | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 46413 | 71 | 1604154 | 184 | 100 | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 17462 | 34 | 31367 | 5 | 2 | |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 24668 | 22 | 43103 | 3 | 2 | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 1953 | 4 | 5502 | 1 | 1 | |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 5500 | 7 | 316533 | 32 | 16 | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 9695 | 14 | 311165 | 34 | 12 | |

Appendix D3.5: GC-MS regular terrigenous triterpenoid peak measurement and RCI estimation (sheet 1 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Full Scale Response Counts | | | GC-MS Plot Scale | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | *m/z* 189 (counts) | *m/z* 218 (counts) | *m/z* 243 (counts) | *m/z* 189 (mm) | *m/z* 218 (mm) | *m/z* 243 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 20510 | 11560 | 7944 | 36 | 36 | 36 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 32430 | 71670 | 42570 | 36 | 36 | 36 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 31300 | 44310 | 39460 | 36 | 36 | 36 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 33720 | 51630 | 0 | 36 | 32.5 | *n/a* |
| V714-51 | Ib | F1 | 1993 | GS-4A | 2326 | 1628 | 1276 | 36 | 36 | 36 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 37870 | 19550 | 0 | 36 | 63 | *n/a* |
| L502 | Ia | G6 | 1994 | GMS-32 | 16240 | 22520 | 2275 | 36 | 36 | 36 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 30780 | 52130 | 31240 | 36 | 36 | 36 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 2269 | 3583 | 559 | 36 | 36 | 36 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 22260 | 9375 | 30880 | 36 | 36 | 36 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 9606 | 14710 | 13130 | 36 | 36 | 36 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 29160 | 22520 | 3835 | 36 | 36 | 36 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 32180 | 31890 | 13560 | 36 | 36 | 36 |
| V704-42 | III | G1 | 1993 | GS-9 | 13540 | 10930 | 6538 | 36 | 36 | 36 |
| V704-42 | III | G1 | 1994 | GMS-39 | 0 | 8581 | 0 | *n/a* | 46.5 | *n/a* |
| L535 | III | G1 | 1993 | GS-5 | 22870 | 17640 | 5130 | 36 | 36 | 36 |
| L535 | III | G1 | 1994 | GMS-35 | 14690 | 16030 | 3589 | 36 | 36 | 36 |
| L543 | III | F5 | 1993 | GS-1A | 7324 | 6261 | 2584 | 36 | 36 | 36 |
| L543 | III | F5 | 1994 | GMS-37 | 7966 | 7783 | 2615 | 36 | 36 | 36 |
| L388 | IVb | FX | 1994 | GMS-34 | 6041 | 6029 | 723 | 36 | 36 | 36 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 28730 | 15740 | 3539 | 36 | 36 | 36 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 12200 | 1886 | 1408 | 36 | 36 | 36 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 13630 | 6733 | 3212 | 36 | 36 | 36 |
| B28-57 | Ib | C | 1994 | GMS-31 | 46790 | 22700 | 5168 | 36 | 36 | 36 |
| B28-60 | Ib | C | 1994 | GMS-30 | 22640 | 25740 | 3288 | 36 | 36 | 36 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 69210 | 61390 | 11610 | 36 | 36 | 36 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 25590 | 32400 | 3866 | 36 | 36 | 36 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 141600 | 81990 | 0 | 36 | 32.5 | *n/a* |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 32550 | 20260 | 4998 | 36 | 36 | 36 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 46130 | 88740 | 0 | 36 | 32.5 | *n/a* |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 65910 | 148200 | 0 | 36 | 63 | *n/a* |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 43650 | 62480 | 7676 | 36 | 36 | 36 |

Appendix D3.5: GC-MS regular terrigenous triterpenoid peak measurement and RCI estimation (sheet 2 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | H9 *m/z* 218 (mm) | H28 *m/z* 218 (mm) | H28.2 *m/z* 218 (mm) | H33 *m/z* 218 (mm) | H36 *m/z* 218 (mm) | H37 *m/z* 189 (mm) | H53 *m/z* 218 (mm) | H57 *m/z* 243 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | 22 | | | 2 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | 6 | 5 | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | 8 | | 10 | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | | 12 | 4 | 7 | 32 | 3 | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | 15 | | | 30 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 3 | 4 | | | 60 | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | 3 | 7 | 8 | 10 | 70 | 2 | | 30 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | 14 | | | 1 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | 32 | | | 25 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | 7 | | | 26 | | | 1 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | 5 | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 6 | | 7 | 10 | 70 | | | 31 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | 10 | | | 25 |
| V704-42 | III | G1 | 1993 | GS-9 | | 4 | | | 8 | | | 11 |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | 16 | | | |
| L535 | III | G1 | 1993 | GS-5 | | 4 | 1 | | 35 | | | 33 |
| L535 | III | G1 | 1994 | GMS-35 | | 4 | 3 | 5 | 35 | | | 32 |
| L543 | III | F5 | 1993 | GS-1A | 8 | 16 | | | 34 | | | 32 |
| L543 | III | F5 | 1994 | GMS-37 | | 22 | | 15 | 32 | | | 32 |
| L388 | IVb | FX | 1994 | GMS-34 | | 15 | | | 33 | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 4 | 20 | 3 | 11 | 34 | 26 | | 24 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | 12 | | 15 | 30 | 15 | | 30 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | 17 | | 8 | 30 | 15 | | 22 |
| B28-57 | Ib | C | 1994 | GMS-31 | 11 | 8 | 6 | 11 | 70 | 10 | | 18 |
| B28-60 | Ib | C | 1994 | GMS-30 | 7 | 5 | 6 | 7 | 70 | 6 | | 15 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 7 | 12 | 12 | 19 | 175 | 3 | | 13 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 15 | 4 | 6 | 19 | 70 | 13 | | 12 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 7 | 8 | 3 | 8 | 32 | | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 16 | 10 | 3 | 8 | 34 | 4 | | 7 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 5 | 4 | 2.5 | 4 | 32 | 3 | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 5 | 9 | 4 | 6 | 62 | 6 | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 4 | 6 | 3 | 6 | 35 | 5 | | 20 |

Appendix D3.5: GC-MS regular terrigenous triterpenoid peak measurement and RCI estimation (sheet 3 of 3)

| Coal Sample | | | GC-MS Sample | | Relative Concentration Index Total Regular Triterpenoids | | | |
|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | Response (counts) | RCI | RCI (norm.) | RCI (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 7506 | 105 | 23 | 27 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 16449 | 152 | 33 | 30 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 22155 | 109 | 24 | 13 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 90184 | *n/a* | *n/a* | *n/a* |
| V714-51 | Ib | F1 | 1993 | GS-4A | 1742 | 3 | 1 | 0 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 20791 | 101 | 22 | 25 |
| L502 | Ia | G6 | 1994 | GMS-32 | 64103 | 78 | 17 | 15 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 21141 | 384 | 83 | 100 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 3573 | 8 | 2 | 2 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 9452 | 43 | 9 | 8 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 2043 | 9 | 2 | 2 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 61479 | 82 | 18 | 16 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 18275 | 21 | 4 | 3 |
| V704-42 | III | G1 | 1993 | GS-9 | 5641 | 24 | 5 | 3 |
| V704-42 | III | G1 | 1994 | GMS-39 | 2953 | 6 | 1 | 2 |
| L535 | III | G1 | 1993 | GS-5 | 24303 | 91 | 20 | 17 |
| L535 | III | G1 | 1994 | GMS-35 | 24118 | 87 | 19 | 15 |
| L543 | III | F5 | 1993 | GS-1A | 12384 | 13 | 3 | 2 |
| L543 | III | F5 | 1994 | GMS-37 | 17242 | 20 | 4 | 2 |
| L388 | IVb | FX | 1994 | GMS-34 | 8039 | *n/a* | *n/a* | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 54589 | 65 | 14 | 5 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 9243 | 61 | 13 | 3 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 17929 | 20 | 4 | 2 |
| B28-57 | Ib | C | 1994 | GMS-31 | 82420 | 109 | 23 | 16 |
| B28-60 | Ib | C | 1994 | GMS-30 | 73068 | 144 | 31 | 27 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 393648 | 465 | 100 | 96 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 113130 | 169 | 36 | 26 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 146321 | 100 | 21 | 15 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 44546 | 64 | 14 | 7 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 133541 | 138 | 30 | 25 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 213290 | 239 | 51 | 44 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 104047 | 116 | 25 | 18 |

Appendix D3.6: GC-MS A-ring contracted triterpenoid peak measurement and RCI estimation (sheet 1 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Full Scale Response Counts | | | | GC-MS Plot Scale | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | *m/z* 189 (counts) | *m/z* 191 (counts) | *m/z* 365 (counts) | RIC (counts) | *m/z* 189 (mm) | *m/z* 191 (mm) | *m/z* 365 (mm) | RIC (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 20510 | 15430 | 6940 | 2229000 | 36 | 36 | 36 | 36 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 32430 | 54410 | 17470 | 2399000 | 36 | 36 | 36 | 36 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 31300 | 31480 | 9210 | 2459000 | 36 | 36 | 36 | 36 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 33720 | 78120 | 73020 | 7221000 | 36 | 36 | 36 | 36 |
| V714-51 | Ib | F1 | 1993 | GS-4A | 2326 | 12950 | 1464 | 960400 | 36 | 36 | 36 | 36 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 37870 | 29580 | 21030 | 2174000 | 36 | 36 | 36 | 36 |
| L502 | Ia | G6 | 1994 | GMS-32 | 16240 | 81010 | 23600 | 3806000 | 36 | 36 | 36 | 36 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 30780 | 23040 | 22660 | 2359000 | 36 | 36 | 36 | 36 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 2269 | 4686 | 5287 | 875600 | 36 | 36 | 36 | 36 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 22260 | 37030 | 7865 | 3783000 | 36 | 36 | 36 | 36 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 9606 | 13010 | 2898 | 1941000 | 36 | 36 | 36 | 36 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 29160 | 122400 | 26670 | 15780000 | 36 | 36 | 36 | 36 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 32180 | 261200 | 21410 | 14640000 | 36 | 36 | 36 | 36 |
| V704-42 | III | G1 | 1993 | GS-9 | 13540 | 81740 | 16830 | 6628000 | 36 | 36 | 36 | 36 |
| L535 | III | G1 | 1993 | GS-5 | 22870 | 71630 | 20290 | 4692000 | 36 | 36 | 36 | 36 |
| L535 | III | G1 | 1994 | GMS-35 | 14690 | 86380 | 17370 | 6776000 | 36 | 36 | 36 | 36 |
| L543 | III | F5 | 1993 | GS-1A | 7324 | 31910 | 13070 | 1756000 | 36 | 36 | 36 | 36 |
| L543 | III | F5 | 1994 | GMS-37 | 7966 | 43770 | 5526 | 3730000 | 36 | 36 | 36 | 36 |
| L388 | IVb | FX | 1994 | GMS-34 | 6041 | 101100 | 6243 | 5084000 | 36 | 36 | 36 | 36 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 28730 | 34170 | 68470 | 2975000 | 36 | 36 | 36 | 36 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 12200 | 21820 | 8581 | 2264000 | 36 | 36 | 36 | 36 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 13630 | 35810 | 34780 | 3982000 | 36 | 36 | 36 | 36 |
| B28-57 | Ib | C | 1994 | GMS-31 | 46790 | 109200 | 76950 | 5468000 | 36 | 36 | 36 | 36 |
| B28-60 | Ib | C | 1994 | GMS-30 | 22640 | 61160 | 42970 | 4114000 | 36 | 36 | 36 | 36 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 69210 | 120800 | 222400 | 4676000 | 36 | 36 | 36 | 36 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 25590 | 31010 | 61510 | 2376000 | 36 | 36 | 36 | 36 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 141600 | 75440 | 270200 | 12390000 | 36 | 36 | 36 | 36 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 32550 | 29660 | 54160 | 4401000 | 36 | 36 | 36 | 36 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 46130 | 105300 | 108900 | 14600000 | 36 | 36 | 36 | 36 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 65910 | 135300 | 112500 | 11600000 | 36 | 36 | 36 | 36 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 43650 | 107800 | 39760 | 6786000 | 36 | 36 | 36 | 36 |

Appendix D3.6: GC-MS A-ring contracted triterpenoid peak measurement and RCI estimation (sheet 2 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | H8.5 *m/z* 189 (mm) | H11a *m/z* 189 (mm) | H15 *m/z* 365 (mm) | H16 *m/z* 365 (mm) | H16 RIC (mm) | H16.2 *m/z* 365 (mm) | H16.8 *m/z* 189 (mm) | H17.2 *m/z* 365 (mm) | H17.4 *m/z* 365 (mm) | H24 *m/z* 365 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | 9 | 35 | 1 | 8 | | | 16 | 6 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | 3 | 35 | 3 | 7 | | 0 | 5 | 2 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | 4 | 33 | 3 | 7 | | 4 | 3.5 | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 1 | 7 | 7 | 70 | 7 | 10 | 5 | 9 | 6 | 2 |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | 8 | 20 | | 13 | | 0 | 0 | |
| V714-72 | Ia | H1 | 1993 | GS-11 | | | 4 | 35 | 5 | 8 | 1 | 0 | 6 | 2 |
| L502 | Ia | G6 | 1994 | GMS-32 | | 6 | 7 | 35 | 3.5 | 9 | 7 | 5 | 5 | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | 3 | 35 | 3 | 6 | 1 | | 5 | 1.5 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | 7 | 35 | 1 | 11 | | 0 | 0 | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | 6 | 35 | 0.5 | 13 | | 0 | 11 | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | 7 | 35 | 1 | 11 | | | 11 | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | 13 | 33 | 1 | 16 | 1 | 5 | 12 | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | 28 | 27 | | 27 | | 6 | 25 | |
| V704-42 | III | G1 | 1993 | GS-9 | | | 1 | 5 | 0.5 | 2 | | 0 | 0 | |
| L535 | III | G1 | 1993 | GS-5 | | | 5 | 35 | 1 | 11 | | 0 | 0 | |
| L535 | III | G1 | 1994 | GMS-35 | | | 9 | 35 | 4 | 10 | 3 | 3 | 6.5 | |
| L543 | III | F5 | 1993 | GS-1A | | 1 | 3 | 35 | 1.5 | 11 | | 0 | 0 | |
| L543 | III | F5 | 1994 | GMS-37 | | | 14 | 70 | 2 | 22 | | 5 | 4 | |
| L388 | IVb | FX | 1994 | GMS-34 | | | 5 | 32 | 1.5 | 7 | | 20 | 4 | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | 3.5 | 5 | 35 | 15 | 9 | 6 | 12 | 6 | 2 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | 13 | 14 | 0.5 | 9 | 4 | 0 | 35 | 15 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | 6 | 10 | 35 | 7 | 12 | 12 | 11 | 8 | 4 |
| B28-57 | Ib | C | 1994 | GMS-31 | | 3 | 5 | 35 | 6 | 9 | 5 | 10 | 5 | 3 |
| B28-60 | Ib | C | 1994 | GMS-30 | | 5 | 5 | 33 | 4.5 | 10 | 6 | 6 | 8 | 2 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 6 | 6 | 6 | 36 | 21 | 11 | 10 | 3 | 9 | 3 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | 5 | 8 | 35 | 13 | 13 | 7 | 5 | 11 | 1 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | | 6 | 36 | 8 | 14 | 1 | 1.5 | 12 | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 10 | 8 | 8 | 35 | 7.5 | 16 | 7 | 3 | 14 | 1 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | | | 5.5 | 36 | 3 | 12 | 3 | 6 | 9 | 1 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | | 1 | 5 | 36 | 4 | 9 | | 15 | 6 | |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | | 1 | 4 | 35 | 3 | 7 | | 15 | 6 | 1 |

Appendix D3.6: GC-MS A-ring contracted triterpenoid peak measurement and RCI estimation (sheet 3 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | Relative Concentration Index Total A-Ring Contracted | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | H31 | X9 | H56 | | | |
| **Unique ID** | **Facies** | **Ply** | **Run** | **File ID** | ***m/z* 365** (mm) | ***m/z* 191** (mm) | ***m/z* 189** (mm) | **Response** (counts) | **RCI** | **RCI** (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 19 | | 4 | 20207 | 28 | 44 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 10 | | 8 | 37294 | 34 | 54 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 6 | | 6 | 19927 | 10 | 15 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 4.5 | | | 232251 | *n/a* | *n/a* |
| V714-51 | Ib | F1 | 1993 | GS-4A | 7 | | | 1952 | 0 | 1 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 5 | | 4 | 40310 | 20 | 31 |
| L502 | Ia | G6 | 1994 | GMS-32 | 6 | | | 49787 | 6 | 10 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 4 | | | 35160 | 64 | 100 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 8 | | | 8959 | 2 | 3 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 4 | | | 15075 | 7 | 11 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | 5152 | 2 | 4 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 4 | | | 62299 | 8 | 13 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | 67204 | 8 | 12 |
| V704-42 | III | G1 | 1993 | GS-9 | | | | 3740 | 2 | 2 |
| L535 | III | G1 | 1993 | GS-5 | 5 | | | 31562 | 12 | 19 |
| L535 | III | G1 | 1994 | GMS-35 | 3 | | | 33310 | 12 | 19 |
| L543 | III | F5 | 1993 | GS-1A | 1.5 | | | 18538 | 2 | 3 |
| L543 | III | F5 | 1994 | GMS-37 | | | | 17653 | 2 | 3 |
| L388 | IVb | FX | 1994 | GMS-34 | | | | 11792 | *n/a* | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 5 | 2 | | 148325 | 18 | 28 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 28 | | | 28529 | 19 | 30 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 11 | | | 94731 | 11 | 17 |
| B28-57 | Ib | C | 1994 | GMS-31 | 2.5 | 4 | | 158954 | 21 | 33 |
| B28-60 | Ib | C | 1994 | GMS-30 | 2 | 4 | | 85696 | 17 | 27 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 9 | | | 517984 | 61 | 96 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 5 | 4 | | 141802 | 21 | 33 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 2 | 2 | | 540581 | 37 | 58 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 4 | 4 | | 144464 | 21 | 32 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 3 | 1 | | 223157 | 23 | 36 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 3.5 | 1 | | 234643 | 26 | 41 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 3 | 1 | | 79628 | 9 | 14 |

Appendix D3.7: GC-MS des-A triterpenoid peak measurement and RCI estimation (sheet 1 of 5)

| Coal Sample | | | GC-MS Sample | | GC-MS Response | | GC-MS Plot Scale | | GC-MS Peak Measurement | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | *m/z* 123 (counts) | RIC (counts) | 123 *m/z* 123 (mm) | RIC RIC (mm) | A20 *m/z* 123 (mm) | A20 RIC (mm) | A25 *m/z* 123 (mm) | A25 RIC (mm) | A30 *m/z* 123 (mm) | A30 RIC (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 2200 | 1346000 | 98 | 98 | 10 | 1.5 | | | 30 | 12 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 3300 | 1689000 | 98 | 98 | | | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 15610 | 2459000 | 98 | 98 | 6 | 2 | | | 4 | 3 |
| V714-51 | Ib | F1 | 1993 | GS-4A | 535 | 516400 | 98 | 98 | | | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | 14290 | 4375000 | 98 | 98 | 30 | 9 | 9 | 1 | 32 | 5 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 2514 | 1176000 | 98 | 98 | 55 | 12 | 20 | 2 | 60 | 25 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 679 | 448500 | 98 | 98 | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | 2577 | 4958000 | 98 | 98 | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 2338 | 6988000 | 98 | 98 | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 13000 | 6005000 | 98 | 98 | | | | | 12 | 4 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 30780 | 3981000 | 98 | 98 | | | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | 2451 | 4376000 | 98 | 98 | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | 4300 | 8641000 | 98 | 98 | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | 2841 | 3595000 | 98 | 98 | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | 4558 | 7339000 | 98 | 98 | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | 735 | 1076000 | 98 | 98 | | | | | 50 | 5 |
| L543 | III | F5 | 1994 | GMS-37 | 4545 | 4643000 | 98 | 98 | 20 | 1.5 | 10 | 0.5 | 45 | 6 |
| L388 | IVb | FX | 1994 | GMS-34 | 3703 | 5084000 | 98 | 98 | 45 | 3 | | | | 1 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 90920 | 2975000 | 98 | 98 | 19 | 51 | 9 | 25 | 8 | 30 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 5576 | 1886000 | 98 | 98 | 5 | 2 | | | | 40 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 25100 | 5210000 | 98 | 98 | 23 | 7 | 6 | 2 | 32 | 18 |
| B28-57 | Ib | C | 1994 | GMS-31 | 26420 | 5468000 | 98 | 98 | 30 | 10 | 12 | 6 | 44 | 27 |
| B28-60 | Ib | C | 1994 | GMS-30 | 15230 | 4482000 | 98 | 98 | 42 | 11 | 26 | 8 | 37 | 14 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 24170 | 2974000 | 98 | 98 | 45 | 25 | 25 | 15 | 45 | 42 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 7575 | 1869000 | 98 | 98 | 25 | 3 | 15 | 1 | 35 | 16 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 15430 | 4401000 | 98 | 98 | 25 | 6 | 15 | 3 | 28 | 11 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 34570 | 6786000 | 98 | 98 | 11 | 4 | 50 | 35 | | |

Appendix D3.7: GC-MS des-A triterpenoid peak measurement and RCI estimation (sheet 2 of 5)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | A32 *m/z* 123 (mm) | A32 RIC (mm) | A34 RIC (mm) | A35 RIC (mm) | A36 *m/z* 123 (mm) | A36 RIC (mm) | A38 RIC (mm) | A40a *m/z* 123 (mm) | A40a RIC (mm) | A40b *m/z* 123 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | 18 | 2 | | 2 | | | | | | |
| V714-66 | Ia | G2 | 1993 | GS-7 | 35 | | | | 30 | 3 | | 40 | 8 | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | 40 | 2 | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | 25 | 1 | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 5 | 7 | | 10 | | | 7 | 20 | 32 | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | | | | | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | | | 2 | | | | 5 | | | |
| B28-57 | Ib | C | 1994 | GMS-31 | | | | | | | | | | |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | 4 | | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | 5 | | 16 | 3 | 11 | | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | | | | | | | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | | | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | | | | | 12 | 2 | | | | |

Appendix D3.7: GC-MS des-A triterpenoid peak measurement and RCI estimation (sheet 3 of 5)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Unique ID** | **Facies** | **Ply** | **Run** | **File ID** | A40X ***m/z* 123** (mm) | A40X **RIC** (mm) | A44 ***m/z* 123** (mm) | A44 **RIC** (mm) | A45 ***m/z* 123** (mm) | A45 **RIC** (mm) | A50a ***m/z* 123** (mm) | A50a **RIC** (mm) | A50b ***m/z* 123** (mm) | A50b **RIC** (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | 3 | | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | 40 | 7 | | | 40 | 4 |
| L502 | Ia | G6 | 1994 | GMS-32 | 15 | 4 | | | | | | | | |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | 40 | 18 | | | 50 | 5 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | 4 | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | 1 | | | | | | | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | 20 | 2 | | | | |
| L543 | III | F5 | 1994 | GMS-37 | 75 | 3 | | | | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | 20 | 1 | | | | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | | | | 20 | | 20 | | | 26 | 41 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | | | | | 12 | 2.5 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 35 | 7 | | | | | | | | |
| B28-57 | Ib | C | 1994 | GMS-31 | 40 | 8 | | | | 12 | 85 | 23 | | |
| B28-60 | Ib | C | 1994 | GMS-30 | 55 | 8 | | | | 13 | 90 | 18 | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 55 | 20 | 30 | 33 | 30 | 47 | | | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 25 | 5 | | | | 11 | | | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 35 | 6 | | | | | | | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 55 | 15 | | | | | | | | |

Appendix D3.7: GC-MS des-A triterpenoid peak measurement and RCI estimation (sheet 4 of 5)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | A60a *m/z* 123 (mm) | A60a RIC (mm) | A60b *m/z* 123 (mm) | A60X *m/z* 123 (mm) | A60X RIC (mm) | A65 RIC (mm) | A70 *m/z* 123 (mm) | A70 RIC (mm) | A72 *m/z* 123 (mm) | A72 RIC (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | | | | | | | | | 35 | 8 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | | | | | | |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | 1 | 0.75 | | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | | | |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | | | |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | | | |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | | | |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | | | |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | | | |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | | | |
| L543 | III | F5 | 1994 | GMS-37 | | | | 55 | 4 | | | | | |
| L388 | IVb | FX | 1994 | GMS-34 | | | | 70 | 1 | | | | | |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 95 | 80 | | | | 4 | 9 | 8 | | |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | | | | | | | | | |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 90 | 14 | | | | 4 | 31 | 1 | 10 | 1 |
| B28-57 | Ib | C | 1994 | GMS-31 | 65 | 20 | | 65 | 20 | 4 | 16 | 2 | | |
| B28-60 | Ib | C | 1994 | GMS-30 | 56 | 11 | | 55 | 10 | | 20 | 1 | 12 | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | | 55 | 25 | 5 | 30 | 5 | | |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | | | | | | | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | | | | |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | | | | 90 | 22 | | 50 | 5 | | |

Appendix D3.7: GC-MS des-A triterpenoid peak measurement and RCI estimation (sheet 5 of 5)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | Relative Concentration Index Total Des-A Triterpenoid | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | A74 *m/z* 123 (mm) | A74 RIC (mm) | A75 *m/z* 123 (mm) | A80 *m/z* 123 (mm) | A80 RIC (mm) | A95 *m/z* 123 (mm) | A95 RIC (mm) | Response (counts) | RCI | RCI (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | | | | | | | 185418 | 26 | 15 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | | | | | | | 0 | 0 | 0 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | | | | | | | 200735 | 10 | 6 |
| V714-51 | Ib | F1 | 1993 | GS-4A | | | | | | | | 36886 | 1 | 0 |
| L502 | Ia | G6 | 1994 | GMS-32 | | | | | | | | 1026786 | 13 | 7 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | | | | | 35 | 3 | 948000 | 172 | 100 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | | | | | | | 18306 | 0 | 0 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | | | | | | | 0 | 0 | 0 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | | | | | | | 0 | 0 | 0 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | | | | | | | | 413610 | 6 | 3 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | | | | | | | 0 | 0 | 0 |
| V704-42 | III | G1 | 1993 | GS-9 | | | | | | | | 0 | 0 | 0 |
| V704-42 | III | G1 | 1994 | GMS-39 | | | | | | | | 0 | 0 | 0 |
| L535 | III | G1 | 1993 | GS-5 | | | | | | | | 0 | 0 | 0 |
| L535 | III | G1 | 1994 | GMS-35 | | | | | | | | 0 | 0 | 0 |
| L543 | III | F5 | 1993 | GS-1A | | | | | | | | 98816 | 1 | 1 |
| L543 | III | F5 | 1994 | GMS-37 | | | | | | | | 710663 | 8 | 5 |
| L388 | IVb | FX | 1994 | GMS-34 | | | | | | | | 363143 | *n/a* | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 17 | 21 | | 22 | 17 | 30 | 55 | 11748214 | 140 | 81 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 90 | 8 | | | | | | 962245 | 64 | 37 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 12 | 3 | | 7 | 1 | 20 | 6 | 3774592 | 42 | 24 |
| B28-57 | Ib | C | 1994 | GMS-31 | | | | 14 | 2 | 50 | 12 | 8146204 | 107 | 62 |
| B28-60 | Ib | C | 1994 | GMS-30 | | | | | | | | 4482000 | 89 | 51 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | | 20 | 5 | 2 | 25 | 10 | 7526041 | 89 | 52 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | | | | | | | | 686571 | 10 | 6 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | | | | | | | | 1167612 | 17 | 10 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | | | | 10 | 2 | 20 | 6 | 6301286 | 71 | 41 |

Appendix D3.8: GC-MS hopanoid peak measurement and RCI estimation (sheet 1 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Response Full Scale Counts | | GC-MS Plot Scale | | GC-MS Peak Measurement | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | H8 | H10 | H20 | H20 | H30 | H32 |
| Unique ID | Facies | Ply | Run | File ID | *m/z* 191 (counts) | RIC (counts) | *m/z* 191 (mm) | RIC (mm) | *m/z* 191 (mm) | *m/z* 191 (mm) | *m/z* 191 (mm) | RIC (mm) | *m/z* 191 (mm) | *m/z* 191 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 15430 | 2229000 | 36 | 36 | | 6 | 19 | 1 | | 4 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 54410 | 2399000 | 36 | 36 | | 2 | 6 | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 31480 | 2459000 | 36 | 36 | | 7 | 11 | 1 | | |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 78120 | 7221000 | 36 | 36 | 4 | 13 | 20 | 2.5 | 2 | 5 |
| V714-51 | Ib | F1 | 1993 | GS-4A | 12950 | 960400 | 36 | 36 | | 3 | 5 | 0.5 | | |
| V714-72 | Ia | H1 | 1993 | GS-11 | 29580 | 2174000 | 36 | 36 | 3 | 6 | 10 | | | 4 |
| L502 | Ia | G6 | 1994 | GMS-32 | 81010 | 3806000 | 36 | 36 | 3 | 8 | 12.5 | 3 | 3 | 1 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 23040 | 2359000 | 36 | 36 | | 6 | 15 | 0.5 | | 5 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 4686 | 875600 | 36 | 36 | | 8 | 25 | 0.5 | | |
| V714-63 | IIa | G3 | 1993 | GS-12 | 37030 | 3783000 | 36 | 36 | | 4 | 7 | | 2 | 3 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 13010 | 1941000 | 36 | 36 | | 15 | 13 | 1 | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 122400 | 15780000 | 36 | 36 | 1 | 6 | 21 | 1.5 | 2 | 1 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 261200 | 14640000 | 36 | 36 | 13 | 4 | 5 | 0.5 | 3 | |
| V704-42 | III | G1 | 1993 | GS-9 | 81740 | 6628000 | 36 | 36 | 1 | 2 | 4 | | 1 | 0.5 |
| L535 | III | G1 | 1993 | GS-5 | 71630 | 4692000 | 36 | 36 | | 3 | 6 | 0.25 | 1.5 | |
| L535 | III | G1 | 1994 | GMS-35 | 86380 | 6776000 | 36 | 36 | | 5 | 7.5 | 1.5 | 1 | 1 |
| L543 | III | F5 | 1993 | GS-1A | 31910 | 1756000 | 36 | 36 | | 5 | 13 | | | |
| L543 | III | F5 | 1994 | GMS-37 | 43770 | 3730000 | 36 | 36 | | 11 | 23 | 3 | | |
| L388 | IVb | FX | 1994 | GMS-34 | 101100 | 5084000 | 36 | 36 | | 1 | 16 | 3 | | 1 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 34170 | 2975000 | 36 | 36 | | 21 | 23 | 4 | 4 | 9 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 21820 | 2264000 | 36 | 36 | | 4 | 13 | 1 | | 2.5 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 35810 | 3982000 | 36 | 36 | | 16 | 27 | 3 | 4 | 6 |
| B28-57 | Ib | C | 1994 | GMS-31 | 109200 | 5468000 | 36 | 36 | 7 | 13 | 20 | 5 | 3 | 5 |
| B28-60 | Ib | C | 1994 | GMS-30 | 61160 | 4114000 | 36 | 36 | | 12 | 17 | 4 | 3 | 5 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 120800 | 4676000 | 36 | 36 | | 12 | 18 | 5 | 4 | 5 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 31010 | 2376000 | 36 | 36 | | 22 | 22 | 5 | 11 | 7 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 75440 | 12390000 | 36 | 36 | 10 | 23 | 21 | 1 | 8 | 5 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 29660 | 4401000 | 36 | 36 | | 32 | 26 | 3 | 9 | 10 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 105300 | 14600000 | 36 | 36 | | 15 | 32 | 2 | 4 | 4 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 135300 | 11600000 | 36 | 36 | 6 | 10 | 28 | 4 | 4 | 5 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 107800 | 6786000 | 36 | 36 | 4 | 10 | 27 | 5 | 2 | 3 |

Appendix D3.8: GC-MS hopanoid peak measurement and RCI estimation (sheet 2 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | H34 *m/z* 191 (mm) | H45 *m/z* 191 (mm) | H45 RIC (mm) | H50 *m/z* 191 (mm) | H55 *m/z* 191 (mm) | H60 *m/z* 191 (mm) | H65 *m/z* 191 (mm) | H70 *m/z* 191 (mm) | H80 *m/z* 191 (mm) | H80 RIC (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | | 10 | | 7 | 5 | 1 | 13 | 6 | 173 | 9 |
| V714-60 | Ib | G4 | 1993 | GS-8 | | 5 | | 1 | 5 | | | 4 | 70 | 10 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | | 7 | | 1 | 10 | | 3 | 4 | 68 | 7 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 4 | 17 | 7 | 4 | 1.5 | 4 | 9 | 3 | 137 | 13 |
| V714-51 | Ib | F1 | 1993 | GS-4A | | 7 | 4.5 | | | 5 | 2 | 4 | 348 | 35 |
| V714-72 | Ia | H1 | 1993 | GS-11 | | 15 | | 4 | 5 | 4 | 5 | 4 | 170 | 17 |
| L502 | Ia | G6 | 1994 | GMS-32 | 4 | 8 | 6 | 3 | 1 | 6 | 5 | 3 | 178 | 26 |
| V714-66 | Ia | G2 | 1993 | GS-7 | | 21 | | 6 | 2 | 4 | 9 | 3 | 175 | 13 |
| V714-56 | IIa | G5 | 1993 | GS-56 | | 16 | 3 | 9 | 2 | 5 | 11 | 9 | 345 | 14.5 |
| V714-63 | IIa | G3 | 1993 | GS-12 | | 10 | | 3 | 1 | 2.5 | 5 | 3 | 174 | 12 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | | 11 | | 1 | | 2 | 3 | 3 | 173 | 8 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 4 | 10 | 2 | 5 | 3 | 5 | 9 | 10 | 350 | 20 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | 5 | 4 | 0.5 | | 6 | 2 | 5 | 175 | 23 |
| V704-42 | III | G1 | 1993 | GS-9 | | 6 | 4 | 1 | 0.5 | 3 | 2 | 1 | 175 | 17 |
| L535 | III | G1 | 1993 | GS-5 | | 20 | 14 | 3 | 1 | 8 | 4 | | 140 | 17 |
| L535 | III | G1 | 1994 | GMS-35 | 1 | 26 | 12.5 | 1 | | 6 | 3 | 2 | 138 | 15 |
| L543 | III | F5 | 1993 | GS-1A | 3 | 10 | 8 | 3 | 2 | 2 | 7 | | 175 | 25 |
| L543 | III | F5 | 1994 | GMS-37 | 6 | 16 | 7 | 5 | 3 | 3 | 8 | 4 | 175 | 17 |
| L388 | IVb | FX | 1994 | GMS-34 | | 2 | 1 | 3 | 1 | | 5 | 8 | 175 | 26 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 8 | 32 | 14 | 6 | 4 | 5 | 10 | 2 | 70 | 5 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | | 18 | | 5 | 1.5 | 3 | 13 | 1.5 | 70 | 5 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 5 | 32 | 11 | 6 | 4 | 8 | 12 | 1 | 75 | 5 |
| B28-57 | Ib | C | 1994 | GMS-31 | 4 | 19 | 17 | 5 | 2.5 | 4 | 9 | 2 | 74 | 10 |
| B28-60 | Ib | C | 1994 | GMS-30 | | 13 | 6 | 6 | 2 | 4 | 9 | 2 | 70 | 8 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | | 16 | 17 | 5 | 2 | 4 | 8 | 2 | 70 | 15 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 9 | 24 | 12 | 7 | 3 | 9 | 11 | 1 | 68 | 8 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | | 28 | 16 | 5 | 2 | 15 | 10 | 3 | 173 | 8 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 7 | 30 | 8 | 6 | 3 | 8 | 10 | | 8 | 0.1 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 4 | 17 | 4 | 7 | 2 | 4 | 14 | 3 | 140 | 9 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 7 | 18 | 8 | 5 | 2 | 4 | 10 | 4 | 180 | 20 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 6 | 16 | 9 | 4 | 1 | 4 | 7 | 3 | 140 | 18 |

Appendix D3.8: GC-MS hopanoid peak measurement and RCI estimation (sheet 3 of 3)

| Coal Sample | | | GC-MS Sample | | GC-MS Peak Measurement | | | Relative Concentration Index | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | H85 | H90 | H95 | Hop-17(21)-ene | | 22R-17α(H),21ß(H)-homohopane | | |
| Unique ID | Facies | Ply | Run | File ID | *m/z* 191 (mm) | *m/z* 191 (mm) | *m/z* 191 (mm) | Response (counts) | RCI (norm.) | Response (counts) | RCI | RCI (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 8 | 5 | 9 | 4286 | 24 | 74150 | 103 | 51 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 3 | 1 | 4 | 7557 | 29 | 105797 | 98 | 48 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 2 | | 2 | 6121 | 12 | 59462 | 29 | 14 |
| V714-69 | Ib | H2 | 1994 | GMS-25 | 7 | 3 | 5 | 36890 | | 297290 | *n/a* | *n/a* |
| V714-51 | Ib | F1 | 1993 | GS-4A | 2 | 3 | 11 | 2518 | 2 | 125183 | 20 | 10 |
| V714-72 | Ia | H1 | 1993 | GS-11 | 7 | 7 | 12 | 12325 | 25 | 139683 | 68 | 34 |
| L502 | Ia | G6 | 1994 | GMS-32 | 4 | 2 | 3 | 18002 | 9 | 400549 | 49 | 24 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 10 | 5 | 15 | 13440 | 100 | 112000 | 203 | 100 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 10 | 6 | 14 | 2083 | 2 | 44908 | 10 | 5 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 4 | 3 | 20 | 10286 | 19 | 178978 | 82 | 40 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 2 | | 7 | 3975 | 7 | 62520 | 28 | 14 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 10 | 10 | 10 | 34000 | 19 | 1190000 | 160 | 78 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | | 3 | 4 | 36278 | 17 | 1269722 | 144 | 71 |
| V704-42 | III | G1 | 1993 | GS-9 | 2 | 8 | 10 | 13623 | 23 | 397347 | 166 | 82 |
| L535 | III | G1 | 1993 | GS-5 | 8 | 3 | 8 | 39794 | 61 | 278561 | 104 | 51 |
| L535 | III | G1 | 1994 | GMS-35 | 5 | 3 | 5 | 62386 | 93 | 331123 | 120 | 59 |
| L543 | III | F5 | 1993 | GS-1A | 10 | 5 | 10 | 8864 | 4 | 155118 | 17 | 8 |
| L543 | III | F5 | 1994 | GMS-37 | 7 | 4 | 5 | 19453 | 9 | 212771 | 25 | 12 |
| L388 | IVb | FX | 1994 | GMS-34 | 4 | 3 | 3 | 5617 | | 491458 | *n/a* | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 8 | | 3 | 30373 | 15 | 66442 | 8 | 4 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 10 | | 6 | 10910 | 30 | 42428 | 28 | 14 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 7 | 3 | 3 | 31831 | 15 | 74604 | 8 | 4 |
| B28-57 | Ib | C | 1994 | GMS-31 | 8 | 2 | 4 | 57633 | 31 | 224467 | 30 | 15 |
| B28-60 | Ib | C | 1994 | GMS-30 | 6 | 1 | 3 | 22086 | 18 | 118922 | 23 | 12 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 5 | 2 | 3 | 53689 | 26 | 234889 | 28 | 14 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 7 | 1 | 4 | 20673 | 13 | 58574 | 9 | 4 |
| B28-23 | Ia | B1-2 | 1994 | GMS-24 | 7 | 3 | 5 | 58676 | 16 | 362531 | 25 | 12 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 8 | | 2 | 24717 | 15 | 6591 | 1 | 0 |
| L618 | IIa | B3-2 | 1994 | GMS-28 | 6 | 3 | 4 | 49725 | 21 | 409500 | 42 | 21 |
| B28-54 | IIa | B3-1 | 1994 | GMS-27 | 8 | 4 | 5 | 67650 | 31 | 676500 | 76 | 37 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 3 | 2 | 4 | 47911 | 22 | 419222 | 47 | 23 |

Appendix D3.9: GC-MS steroid peak measurement and RCI estimation (sheet 1 of 2)

| Coal Sample | | | GC-MS Sample | | GC-MS Full Scale Response Counts | | GC-MS Peak Measurement | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unique ID | Facies | Ply | Run | File ID | *m/z* 257 (counts) | *m/z* 257 (mm) | I2 *m/z* 257 (mm) | I4 *m/z* 257 (mm) | I10 *m/z* 257 (mm) | I20 *m/z* 257 (mm) | I40 *m/z* 257 (mm) | I45 *m/z* 257 (mm) | I50 *m/z* 257 (mm) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 8312 | 36 | | | | 5 | | 31 | 4 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 44990 | 36 | | | | 1 | | | |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 38700 | 36 | | | | 3 | | | |
| V714-51 | Ib | F1 | 1993 | GS-4A | 1785 | 36 | | | | 32 | | | |
| L502 | Ia | G6 | 1994 | GMS-32 | 26080 | 36 | 10 | 10 | 9 | 70 | 7 | | 5 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 33570 | 36 | | | | 3.5 | | 4 | 1 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 1376 | 36 | | 10 | | 30 | | 30 | 15 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 46930 | 36 | | | | | | | |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 11680 | 36 | | 5 | | 12 | | | |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 39080 | 36 | | 10 | 5 | 35 | 10 | | 6 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 210800 | 36 | 8 | 13 | 5 | 35 | | | |
| V704-42 | III | G1 | 1993 | GS-9 | 13180 | 36 | 8 | 11 | 3 | 35 | | 5 | 2 |
| V704-42 | III | G1 | 1994 | GMS-39 | 13250 | 46.5 | 10 | 18 | 5 | 45 | 4 | | 1 |
| L535 | III | G1 | 1993 | GS-5 | 5293 | 36 | | 5 | | 35 | | 16 | 14 |
| L535 | III | G1 | 1994 | GMS-35 | 5413 | 36 | | 8 | 4 | 33 | | | |
| L543 | III | F5 | 1993 | GS-1A | 1785 | 36 | | | | 22 | | 17 | 8 |
| L543 | III | F5 | 1994 | GMS-37 | 2338 | 36 | | 12 | | 32 | 15 | | |
| L388 | IVb | FX | 1994 | GMS-34 | 1269 | 36 | | | | | 30 | | 30 |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 11270 | 36 | | 3 | | 27 | 35 | | 15 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 5884 | 36 | | | | 11 | | 34 | 16 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 26200 | 36 | 1 | 2 | 3 | 32 | 25 | | 15 |
| B28-57 | Ib | C | 1994 | GMS-31 | 39420 | 36 | 4 | 5 | 6 | 70 | 13 | | 4 |
| B28-60 | Ib | C | 1994 | GMS-30 | 17430 | 36 | | 6 | 3 | 33 | 13 | | |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 48260 | 36 | | 4 | 4 | 35 | 21 | | 4 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 16690 | 36 | 7 | 11 | 6 | 70 | 14 | | |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 19160 | 36 | | 5 | 4 | 34 | 13 | | 3 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 11610 | 36 | 4 | 4 | 5 | 33 | 21 | | 8 |

Appendix D3.9: GC-MS steroid peak measurement and RCI estimation (sheet 2 of 2)

| Coal Sample | | | GC-MS Sample | | RCI - All Steroids | |
|---|---|---|---|---|---|---|
| **Unique ID** | **Facies** | **Ply** | **Run** | **File ID** | **Response** (counts) | **RCI** (norm.) |
| V714-54 | Ic | G6 | 1993 | GS-10 | 9236 | 32 |
| V714-60 | Ib | G4 | 1993 | GS-8 | 1250 | 3 |
| V714-60 | Ib | G4 | 1994 | GMS-40;2 | 3225 | 4 |
| V714-51 | Ib | F1 | 1993 | GS-4A | 1587 | 1 |
| L502 | Ia | G6 | 1994 | GMS-32 | 80413 | 24 |
| V714-66 | Ia | G2 | 1993 | GS-7 | 7926 | 35 |
| V714-56 | IIa | G5 | 1993 | GS-56 | 3249 | 2 |
| V714-63 | IIa | G3 | 1993 | GS-12 | 0 | 0 |
| V714-63 | IIa | G3 | 1994 | GMS-40;1 | 5516 | 6 |
| V704-31 | IIb | G5 | 1994 | GMS-22 | 71647 | 24 |
| V714-50 | IIb | F2 | 1994 | GMS-20S | 357189 | 100 |
| V704-42 | III | G1 | 1993 | GS-9 | 23431 | 24 |
| V704-42 | III | G1 | 1994 | GMS-39 | 23651 | 12 |
| L535 | III | G1 | 1993 | GS-5 | 10292 | 10 |
| L535 | III | G1 | 1994 | GMS-35 | 6766 | 6 |
| L543 | III | F5 | 1993 | GS-1A | 2330 | 1 |
| L543 | III | F5 | 1994 | GMS-37 | 3832 | 1 |
| L388 | IVb | FX | 1994 | GMS-34 | 2115 | *n/a* |
| L610 | Ic | B1-3 | 1994 | GMS-36 | 25044 | 7 |
| B28-6 | Ib | B1-4 | 1993 | GS-3 | 9970 | 16 |
| B28-4 | Ib | B1-4 | 1994 | GMS-23 | 56767 | 16 |
| B28-57 | Ib | C | 1994 | GMS-31 | 111690 | 36 |
| B28-60 | Ib | C | 1994 | GMS-30 | 26629 | 13 |
| L613 | Ib | B1-1 | 1994 | GMS-26R | 91158 | 27 |
| L616 | Ib | B3-4 | 1994 | GMS-29 | 50070 | 18 |
| L612 | IIa | B1-3 | 1994 | GMS-33 | 31401 | 11 |
| B28-54 | IIa | B3-1 | 1994 | GMS-38 | 24188 | 7 |

Key to Appendix D3:

norm. = normalised RCI whereby values are expressed as percentage of the largest RCI response

*n/a* - denotes value not available

FX ply in sample L388, indicates an undifferentiated F Seam ply

# APPENDIX E
# CHEMICAL AND MINERAL ANALYSIS

The kaolinite estimation methodology, data from chemical analysis and quartz and kaolinite mineral estimates by seam are presented in Appendix E.

**APPENDIX E1: Quartz and kaolinite estimation methodology**

Outlines the methodology for estimation of quartz and kaolinite from ash analysis. The accuracy of estimates and their applicability is also reviewed.

**APPENDIX E2: Analytical data from coal chemistry**

Presents analytically determined data from assorted chemical tests including proximate and ultimate analysis, ash composition, acid soluble inorganics, sulphur and where available quartz. Estimated quartz and kaolinite from ash composition analysis are also included.

**APPENDIX E3: Quartz and kaolinite mineral estimates**

Presents seam average quartz and kaolinite mineral estimates from ash composition data.

# APPENDIX E1
# QUARTZ AND KAOLINITE ESTIMATION METHODOLOGY

### *Background*

Petrographic evaluation of coals, while enabling a gross estimate of mineral content, provides very limited quantitative data on individual mineral species present. Furthermore, mineral assessment using SEM/EDS and XRD techniques (Readett and Quast, 1987; Manuel and Quast, 1990; Quast and Readett, 1991) and an XRD investigation of Ward (1992), while unambiguously identifying the species present, provides only quantitative data on mineral abundance. To study the nature and distribution of syngenetic crystalline minerals potentially applicable for palaeoenvironmental assessment (viz. quartz and kaolinite) manipulation of chemical test data from coal cores was undertaken.

An extensive analytical data set fully covering the full vertical and lateral extent of the seam was routinely collected for resource evaluation of the Lochiel and Bowmans Deposits. Data of particular significance were ash content and ash composition based on testing of the inorganic residue after coal incineration. In addition, direct chemical analysis for quartz during the current research provided supplementary data for verification of the mineral estimation procedure.

Ash products generated from combustion of brown coals are formed from minerals within the coal (e.g. quartz, kaolinite and pyrite); inorganics such as acid extractable and soluble salts of sodium, calcium, magnesium, iron and chlorine, and sulphur which has reacted with some of the inorganics (King *et al.*, 1983). The ash of brown coals is therefore not necessarily a direct indication of crystalline mineral content within the coal, particularly in high-sulphur and inorganic-rich coals such as those from the Lochiel and Bowmans Deposits. Furthermore, assorted chemical changes occur during coal combustion and ash formation. Rance (1975) highlighted loss of water from hydrated complexes, loss of carbon dioxide from carbonates, oxidation of pyrite to iron sulphates and iron oxides, fixation of sulphur by bases such as calcium and magnesium oxides and volatilisation and decomposition of alkali chlorides.

Quantitative quartz determinations and assorted investigation of mineral occurrence within northern St. Vincent Basin coals lead to the development by the former Electricity Trust of South Australia (ETSA) of a procedure for estimating quartz and kaolinite abundance from ash composition. However, as noted above, a number of chemical changes occur during combustion and the estimation represents on an approximation of possible mineral abundance within the raw coal state.

***Methodology***

The methodology outlined in this appendix and used during this research follows the approach applied by ETSA (J. Vingelis, pers. comm., 1990).

Depending on the relative abundance of $SiO_2$ and $Al_2O_3$, two methods were used to estimate quartz and kaolinite abundance. $SiO_2$ occurs in both minerals and assessment of the ratio is necessary to first determine the appropriate allocation of $SiO_2$ (i.e. to quartz or kaolinite).

***Step 1***

Test the ratio of $SiO_2/Al_2O_3$ and compare with the corresponding molecular weight ratio within kaolinite (i.e. 1.176).

Kaolinite $= Al_4(Si_4O_{10})(OH)_8$

*where:*

*chemical components* = $2x(Al_2O_3)$ $4x(SiO_2)$ $4xH_2O$

204 240 72 *(molecular weight for each group)*

240/204=1.176 *(molecular weight ratio of $SiO_2/Al_2O_3$ in kaolinite)*

***Step 2***

Determine procedure to be used for kaolinite and quartz estimation.

If $SiO_2/Al_2O_3$ is $\geq 1.176$, then sufficient $SiO_2$ is available to allocate all $Al_2O_3$ to kaolinite, with the remaining $SiO_2$ allocated to quartz. Refer to step 3 for this procedure.

If $SiO_2/Al_2O_3$ is $< 1.176$ then insufficient $SiO_2$ is available to allocate all $Al_2O_3$ to kaolinite. However, minor quartz is normally detected and a small component is assumed based on analytical deposit averages (i.e. Lochiel Deposit = 0.3% (db), Bowmans Deposit = 0.2% (db)). The remaining $SiO_2$ is allocated to kaolinite and the additional $Al_2O_3$ estimated. Refer to step 4 for this procedure.

***Step 3***

Estimate kaolinite and quartz for $SiO_2/Al_2O_3 \geq 1.176$.

Allocate all $Al_2O_3$ to kaolinite:

Kaolinite = $[Al_2O_3 + Al_2O_3 \times (240/204) + Al_2O_3 \times (72/204)] \times (ash/100)$

*total $Al_2O_3$* *$SiO_2$ in kaolinite* *$H_2O$ in kaolinite*

Allocate remaining $SiO_2$ to quartz:

Quartz = $(SiO_2 - Al_2O_3 \times (240/204)) \times (ash/100)$

*total $SiO_2$* *$SiO_2$ in kaolinite*

Proceed to step 5.

***Step 4***

Estimate kaolinite and quartz for $SiO_2/Al_2O_3 < 1.176$.

Assume the quartz content based on deposit averages for this subset (i.e. Lochiel O.3%, Bowmans O.2% db).

Assess the remaining $SiO_2$ (i.e. Y1), which can be allocated to kaolinite by removing that portion occurring as quartz. As $SiO_2$ is reported as percent within the ash, while quartz is reported as percent in dry coal, the two are standardised and the difference evaluated as percent in ash:

$$Y1 = SiO_2 - (\text{quartz} \times 100) / \text{ash}$$

In some instances a negative "free $SiO_2$" resulted, indicating assumed deposit values of quartz were too high. Where this occurred a 0.1% quartz content was assumed.

Estimate kaolinite in line with remaining $SiO_2$:

$$\text{Kaolinite} = (Y1 \times (204/240) + Y1 + Y1 \times (72/240)) \times (\text{ash}/100)$$

*$Al_2O_3$ equiv. remain. $SiO_2$ $H_20$ equiv.*

Remaining $Al_2O_3$ is assumed to occur in ion exchangable form.

***Accuracy of Estimates***

The accuracy and consistency of mineral estimates cannot be fully quantified and several assumptions are involved in their formulation. However, some comparisons were possible against analytical determinations.

A large number of chemically determined quartz values are available in both deposits. Comparisons against estimates using the procedure outlined above suggest generally good agreement, with correlation coefficients exceeding 0.99 in both deposits (Figure E3.1).

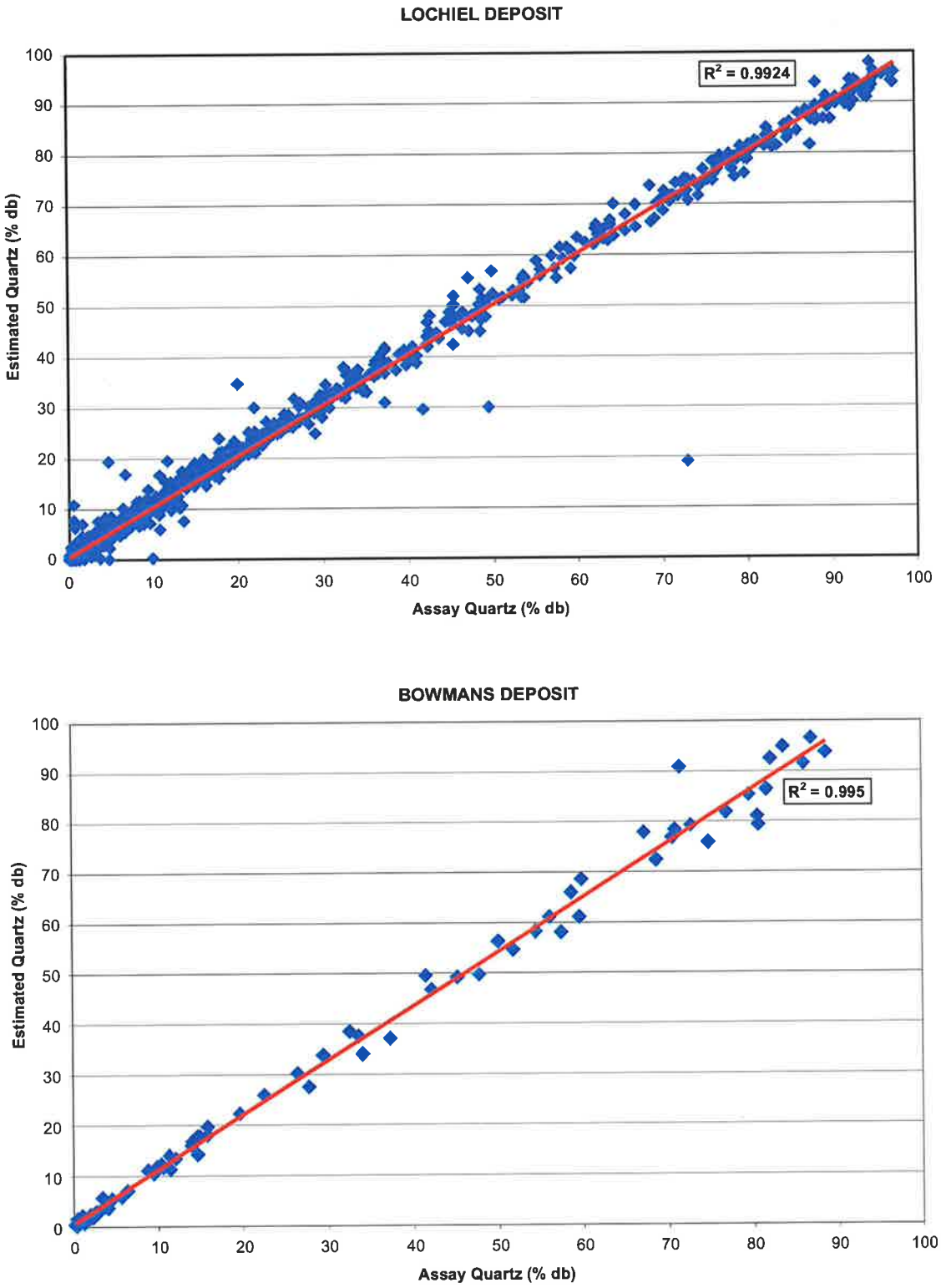



Figure E1.1 Comparison between chemically determined and estimated quartz

Evaluation of spatial models of ash constituents, relative to mineral estimates, was also possible for each of the seams. Matching model sets consistently show good agreement with respect to regional trends and areas of high/low relative abundance. An example is presented in Figure E1.2, where chemically determined $SiO_2$ vs. estimated quartz and chemically determined $Al_2O_3$ vs. estimated kaolinite are shown for G Seam, Lochiel Deposit.

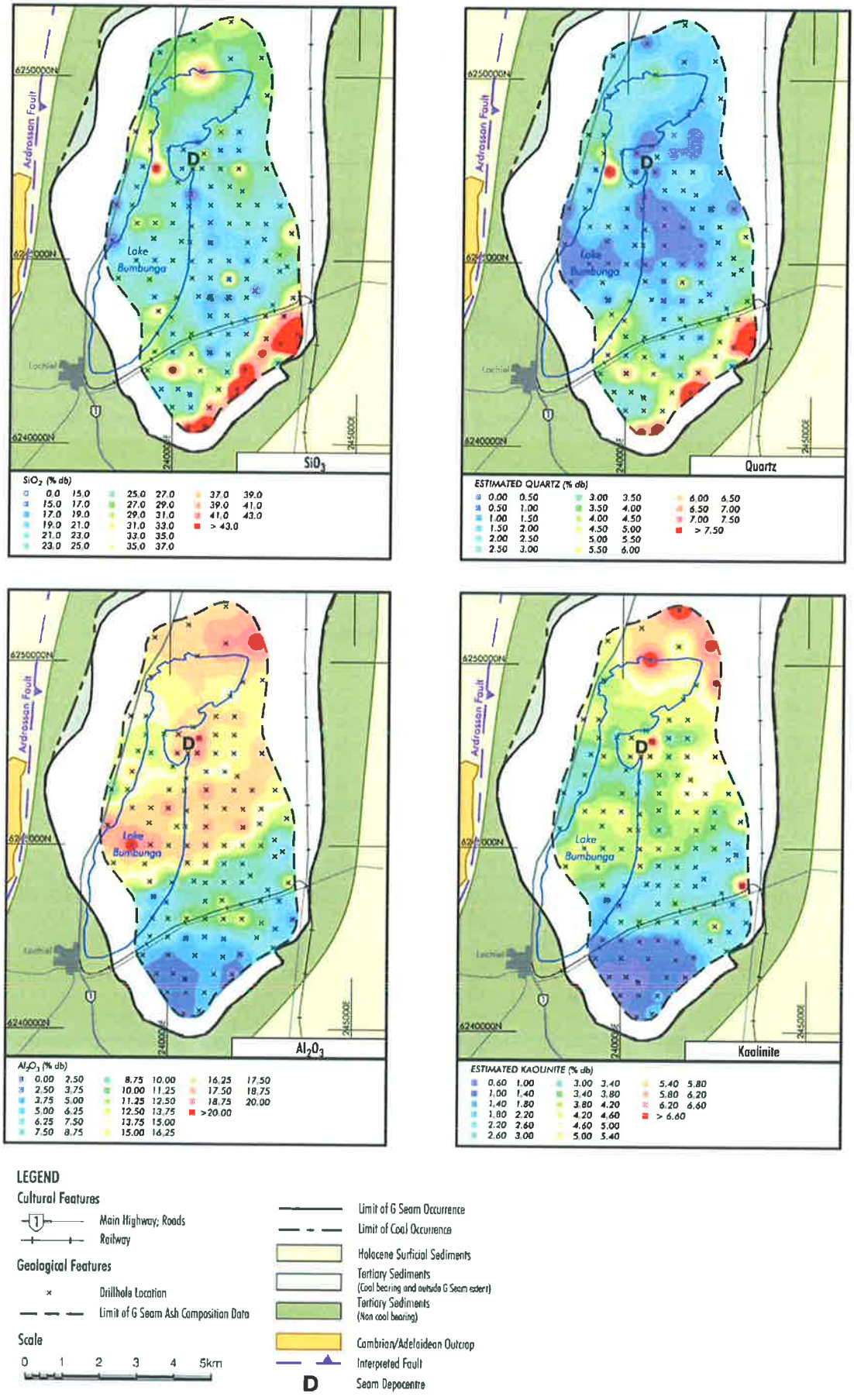



Figure E1.2 Comparison of chemically determined $SiO_2$ and $Al_2O_3$ with estimated quartz and kaolinite abundance

In summary, the mineral estimation approach, while an approximation, shows reasonable agreement with analytically determined values. Furthermore results appear satisfactory for meeting the objectives of the current research project (viz. assessment of gross quartz and kaolinite abundance (for facies, seam and deposit comparison) and the evaluation of regional trends in mineral distribution.

Appendix E2: Analytical data from coal chemistry (sheet 1 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 |
| Sample | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 |
| Depth | 53.75 | 54.25 | 54.75 | 55.25 | 55.75 | 56.15 | 57.05 | 57.55 | 58.05 | 58.45 |
| Seam | F | F | F | F | F | F | G | G | G | G |
| Ply | F-3 | F-2 | F-2 | F-2 | F-1 | F-1 | G-6 | G-6 | G-6 | G-5 |
| Facies | Ib | Ib | IIb | IIb | Ib | Ib | Ic | Ic | Ic | IIb |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 61.5 | 61.9 | 63.2 | 63.1 | 60.5 | 62 | 49.1 | 49 | 50.3 | 57.6 |
| Ash (% db) | 14.35 | 12.03 | 10.78 | 11.97 | 14.21 | 20.52 | 12.37 | 10.22 | 11.07 | 10.98 |
| Volatile matter (% db) | 45.25 | 45.52 | 46.09 | 46.61 | 47.9 | 41.63 | 59.43 | 60.67 | 56.23 | 48.69 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 55.44 | 58.11 | 60.01 | 58.25 | 56.53 | 54.73 | 60.78 | 62.2 | 61.77 | 60.26 |
| Hydrogen (% db) | 3.77 | 3.93 | 3.95 | 4.05 | 4.17 | 3.76 | 5.54 | 5.57 | 5.36 | 4.4 |
| Nitrogen (% db) | | 0.6 | | 0.5 | | | | 0.3 | | 0.6 |
| Sulphur (% db) | 3.2 | 2.96 | 3.12 | 3.08 | 3.15 | 3 | 2.7 | 2.59 | 2.63 | 2.9 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.01 | 0.01 | 0.05 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.06 | 0.07 |
| Sulphate (% db) | 0.17 | 0.11 | 0.13 | 0.18 | 0.15 | 0.14 | 0.06 | 0.07 | 0.08 | 0.11 |
| Organic (% db) | 3.03 | 2.85 | 2.94 | 2.87 | 2.98 | 2.84 | 2.64 | 2.5 | 2.49 | 2.72 |
| HHV (MJ/kg db) | 21.21 | 22.81 | 23.32 | 22.78 | 22.4 | 21.07 | 26.46 | 26.56 | 25.43 | 23.64 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.51 | 0.22 | 1.22 | 0.41 | 0.6 | 0.54 | 0.12 | 0.43 | 1.37 | 1.58 |
| $Al_2O_3$ (% db) | 25.42 | 20.57 | 18.94 | 25.21 | 21.73 | 9.34 | 19.36 | 20.45 | 19.56 | 19.67 |
| $SiO_2$ (% db) | 22 | 14.75 | 13.4 | 16.05 | 29.2 | 59.8 | 38.4 | 24.05 | 22.2 | 15.85 |
| MgO (% db) | 11.06 | 12.6 | 12.56 | 11.3 | 11.16 | 6.15 | 10.5 | 13.74 | 14.94 | 15.76 |
| Ca0 (% db) | 8.17 | 9.29 | 9.1 | 7.87 | 7.7 | 4.26 | 8.15 | 10.55 | 10.98 | 11.3 |
| $K_2O$ (% db) | 0.51 | 0.99 | 0.34 | 1.35 | 0.24 | 0.13 | 0.15 | 0.21 | 0.21 | 0.27 |
| $Na_2O$ (% db) | 11.72 | 14.05 | 16.28 | 14.8 | 10.81 | 6.57 | 8.34 | 10.63 | 10.42 | 12.25 |
| $SO_3$ (% db) | 17.8 | 24.84 | 25.5 | 20.73 | 16.36 | 13.05 | 13.23 | 17 | 18.8 | 21.56 |
| $TiO_2$ (% db) | 0.15 | 0.15 | 0.1 | 0.1 | 0.24 | 0.19 | 0.56 | 0.56 | 0.39 | 0.19 |
| $SiO_2/Al_2O_3$ | 0.9 | 0.7 | 0.7 | 0.6 | 1.3 | 6.4 | 2.0 | 1.2 | 1.1 | 0.8 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.04 | 0.02 | 0.01 | 0.01 | 0.04 | 0.04 | 0.01 | 0.01 | 0.03 | 0.03 |
| Al (% db) | 0.99 | 0.82 | 0.58 | 0.47 | 0.57 | 0.57 | 0.46 | 0.32 | 0.35 | 0.38 |
| Si (% db) | 0.44 | 0.31 | 0.15 | 0.08 | 0.25 | 0.22 | 0.27 | 0.11 | 0.13 | 0.05 |
| Mg (% db) | 0.95 | 0.9 | 0.81 | 0.79 | 0.94 | 0.82 | 0.79 | 0.81 | 0.91 | 1.01 |
| Ca (% db) | 0.86 | 0.8 | 0.73 | 0.69 | 0.81 | 0.71 | 0.75 | 0.77 | 0.87 | 0.94 |
| K (% db) | 0.06 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Na (% db) | 1.29 | 1.26 | 1.3 | 1.24 | 1.19 | 1.18 | 0.82 | 0.81 | 0.86 | 1.11 |
| Cl (% db) | 0.7 | 0.68 | 0.76 | 0.71 | 0.68 | 0.67 | 0.41 | 0.4 | 0.41 | 0.54 |
| Assay quartz (% db) | | | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 6.1 | 3.2 | 2.5 | 3.5 | 7.8 | 4.8 | 6.1 | 5.3 | 4.6 | 3.1 |
| Quartz (% db) | 0.3 | 0.3 | 0.3 | 0.3 | 0.5 | 10.0 | 1.9 | 0.0 | 0.3 | 0.3 |
| Quartz/kaolinite | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 2.1 | 0.3 | 0.0 | 0.1 | 0.1 |

Appendix E2: Analytical data from coal chemistry (sheet 2 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 |
| Sample | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 |
| Depth | 59.05 | 59.45 | 60.05 | 60.55 | 61.05 | 61.55 | 62.05 | 62.60 | 63.10 | 63.55 |
| Seam | G | G | G | G | G | G | G | G | G | G |
| Ply | G-4 | G-4 | G-4 | G-4 | G-3 | G-3 | G-3 | G-2 | G-2 | G-2 |
| Facies | Ib | Ib | Ib | Ib | IIa | IIa | IIa | Ia | Ia | Ia |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 56.1 | 50.5 | 55 | 54.6 | 58.4 | 60.4 | 61.3 | 60.1 | 60.5 | 60.3 |
| Ash (% db) | 11.05 | 10.39 | 10.29 | 9.87 | 10.74 | 10.6 | 11.07 | 10.55 | 9.61 | 10.39 |
| Volatile matter (% db) | 48.53 | 51.62 | 55.38 | 54.67 | 50.88 | 50.43 | 47.64 | 50.75 | 55.25 | 51.32 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 60.37 | 61.83 | 62.26 | 62.31 | 60.82 | 60.73 | 59.96 | 61.07 | 62.36 | 60.72 |
| Hydrogen (% db) | 4.55 | 5.03 | 5.18 | 5.17 | 4.62 | 4.57 | 4.34 | 4.58 | 5.24 | 4.7 |
| Nitrogen (% db) | | | 0.6 | 0.5 | | | | | 0.6 | |
| Sulphur (% db) | 3.61 | 2.64 | 2.81 | 2.62 | 3 | 2.87 | 2.93 | 2.78 | 2.76 | 3.06 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.27 | 0.07 | 0.05 | 0.04 | 0.13 | 0.06 | 0.11 | 0.05 | 0.04 | 0.13 |
| Sulphate (% db) | 0.11 | 0.11 | 0.09 | 0.09 | 0.12 | 0.11 | 0.12 | 0.13 | 0.12 | 0.13 |
| Organic (% db) | 3.23 | 2.46 | 2.67 | 2.49 | 2.75 | 2.7 | 2.7 | 2.63 | 2.6 | 2.8 |
| HHV (MJ/kg db) | 24.14 | 24.69 | 25.05 | 25.16 | 23.68 | 23.88 | 22.75 | 23.5 | 25.28 | 24.48 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 8.84 | 1.8 | 1.28 | 1.3 | 2.71 | 1.27 | 1.98 | 1.61 | 1.65 | 2.6 |
| $Al_2O_3$ (% db) | 15.28 | 16.14 | 16.84 | 15.22 | 15.97 | 16.5 | 17.05 | 17.02 | 14.78 | 12.72 |
| $SiO_2$ (% db) | 13.95 | 17.55 | 15.25 | 13.6 | 12.65 | 14.95 | 13.55 | 12.4 | 14.15 | 11.9 |
| MgO (% db) | 15.1 | 16.34 | 16.3 | 16.58 | 15.39 | 15.15 | 16 | 14.43 | 14.46 | 14.35 |
| Ca0 (% db) | 10.88 | 12.1 | 12.23 | 12.58 | 12.05 | 11.8 | 12.62 | 11.5 | 11.79 | 11.25 |
| $K_2O$ (% db) | 0.19 | 0.19 | 0.24 | 0.96 | 0.3 | 0.22 | 0.28 | 0.25 | 0.23 | 0.24 |
| $Na_2O$ (% db) | 11 | 10.86 | 12.62 | 12.96 | 12.9 | 13.45 | 13.22 | 13.96 | 13.67 | 13.92 |
| $SO_3$ (% db) | 23.62 | 23.12 | 23.19 | 24.71 | 25.75 | 24.68 | 24.36 | 26.21 | 27.02 | 30.63 |
| $TiO_2$ (% db) | 0.25 | 0.39 | 0.22 | 0.25 | 0.14 | 0.13 | 0.1 | 0.15 | 0.4 | 0.5 |
| $SiO_2/Al_2O_3$ | 0.9 | 1.1 | 0.9 | 0.9 | 0.8 | 0.9 | 0.8 | 0.7 | 1.0 | 0.9 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 | 0.01 | 0.02 | 0.06 | 0.06 | 0.07 |
| Al (% db) | 0.36 | 0.36 | 0.33 | 0.3 | 0.35 | 0.45 | 0.43 | 0.39 | 0.3 | 0.35 |
| Si (% db) | 0.08 | 0.11 | 0.06 | 0.04 | 0.03 | 0.1 | 0.08 | 0.04 | 0.04 | 0.05 |
| Mg (% db) | 1 | 0.92 | 0.96 | 0.97 | 1.04 | 0.99 | 1.08 | 0.92 | 0.84 | 0.93 |
| Ca (% db) | 0.93 | 0.86 | 0.92 | 0.89 | 0.97 | 0.91 | 0.99 | 0.86 | 0.81 | 0.88 |
| K (% db) | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Na (% db) | 1.04 | 0.89 | 0.95 | 0.99 | 1.1 | 1.1 | 1.16 | 1.07 | 1.01 | 1.08 |
| Cl (% db) | 0.48 | 0.4 | 0.48 | 0.47 | 0.51 | 0.57 | 0.59 | 0.54 | 0.55 | 0.55 |
| Assay quartz (% db) | | | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 2.7 | 3.3 | 2.7 | 2.2 | 2.3 | 2.8 | 2.6 | 2.2 | 2.3 | 2.0 |
| Quartz (% db) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Quartz/kaolinite | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

Appendix E2: Analytical data from coal chemistry (sheet 3 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V714 | V706 | V706 |
| Sample | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | L 540 | L 541 |
| Depth | 64.00 | 66.75 | 67.25 | 67.70 | 68.25 | 68.75 | 69.25 | 69.65 | 54.35 | 55.10 |
| Seam | G | H | H | H | H | H | H | H | F | F |
| Ply | G-1 | H-2 | H-2 | H-1b | H-1b | H-1b | H-1b | H-1a | F-5 | F-5 |
| Facies | III | Ib | Ib | Ic | Ia | Ia | Ia | Ia | III | III |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 63.4 | 62.3 | 61 | 58.2 | 58.1 | 59 | 61.3 | 50.7 | 44.4 | 44.68 |
| Ash (% db) | 17.05 | 11.02 | 11.56 | 13.27 | 16.62 | 13.65 | 12.69 | 39.02 | 49.09 | 30.22 |
| Volatile matter (% db) | 45.85 | 46.9 | 50.38 | 52.76 | 46.8 | 48.12 | 46.35 | 33.48 | 33.17 | 39.2 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 55.17 | 59.19 | 59.41 | 59.9 | 56.13 | 58.98 | 58.84 | 40.4 | | |
| Hydrogen (% db) | 3.86 | 4.3 | 4.57 | 4.98 | 4.17 | 4.56 | 4.35 | 3.11 | | |
| Nitrogen (% db) | 0.6 | | | 0.5 | | 0.5 | 0.5 | | | |
| Sulphur (% db) | 3.27 | 2.87 | 2.79 | 2.48 | 2.44 | 2.47 | 2.62 | 1.76 | 1.87 | 2.93 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.1 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | | |
| Sulphate (% db) | 0.11 | 0.08 | 0.11 | 0.07 | 0.08 | 0.08 | 0.13 | 0.07 | | |
| Organic (% db) | 3.06 | 2.79 | 2.66 | 2.41 | 2.36 | 2.39 | 2.44 | 1.68 | | |
| HHV (MJ/kg db) | 21.43 | 22.4 | 23.13 | 24.3 | 22.05 | 23.22 | 23.09 | 15.95 | 14.53 | 18.04 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 1.77 | 0.11 | 0.82 | 0.08 | 0.16 | 0.11 | 1.14 | 0.15 | 0.16 | 0.08 |
| $Al_2O_3$ (% db) | 23.65 | 15.66 | 18.25 | 10.85 | 9.34 | 10.95 | 16.88 | 3.48 | 3.67 | 11.36 |
| $SiO_2$ (% db) | 30.85 | 15.45 | 23.3 | 44.6 | 52.5 | 41.55 | 29.65 | 81.6 | 86.2 | 68.2 |
| MgO (% db) | 9.52 | 14.75 | 13.14 | 9.2 | 7.15 | 9.5 | 10.26 | 2.49 | 1.82 | 5.28 |
| Ca0 (% db) | 7.04 | 12.55 | 11.1 | 8.08 | 6.29 | 8.5 | 8.92 | 2.24 | 1.54 | 4.12 |
| $K_2O$ (% db) | 1.65 | 0.27 | 0.22 | 0.15 | 0.12 | 0.16 | 0.19 | 0.04 | 0.05 | 0.08 |
| $Na_2O$ (% db) | 8.71 | 13.1 | 11.46 | 8.4 | 6.82 | 8.84 | 10.3 | 2.26 | 1.24 | 3.45 |
| $SO_3$ (% db) | 12.65 | 25.94 | 19.77 | 15.49 | 14.52 | 17.57 | 20.21 | 4.3 | 1.41 | 3.9 |
| $TiO_2$ (% db) | 2.38 | 0.13 | 0.44 | 1.73 | 2.45 | 2.1 | 0.48 | 1.14 | 3.68 | 3.05 |
| $SiO_2/Al_2O_3$ | 1.3 | 1.0 | 1.3 | 4.1 | 5.6 | 3.8 | 1.8 | 23.4 | 23.5 | 6.0 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.03 | 0.01 | 0.04 | 0.01 | 0.01 | 0.01 | 0.07 | 0.03 | 0.02 | 0.02 |
| Al (% db) | 0.28 | 0.36 | 0.28 | 0.22 | 0.29 | 0.29 | 0.32 | 0.2 | 0.49 | 1.05 |
| Si (% db) | 0.04 | 0.02 | 0.03 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.32 | 0.68 |
| Mg (% db) | 0.93 | 1.02 | 0.9 | 0.73 | 0.71 | 0.79 | 0.81 | 0.57 | 0.53 | 0.91 |
| Ca (% db) | 0.86 | 1.02 | 0.89 | 0.75 | 0.75 | 0.82 | 0.84 | 0.59 | 0.5 | 0.85 |
| K (% db) | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | | |
| Na (% db) | 1.09 | 1.08 | 0.98 | 0.86 | 0.88 | 0.91 | 1.01 | 0.62 | 0.48 | 0.78 |
| Cl (% db) | 0.57 | 0.55 | 0.53 | 0.48 | 0.44 | 0.44 | 0.51 | 0.3 | 0.33 | 0.48 |
| Assay quartz (% db) | | | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 10.2 | 3.0 | 5.3 | 3.6 | 3.9 | 3.8 | 5.4 | 3.4 | 4.6 | 8.7 |
| Quartz (% db) | 0.5 | 0.3 | 0.2 | 4.2 | 6.9 | 3.9 | 1.2 | 30.2 | 40.2 | 16.6 |
| Quartz/kaolinite | 0.1 | 0.1 | 0.0 | 1.2 | 1.8 | 1.0 | 0.2 | 8.8 | 8.8 | 1.9 |

Appendix E2: Analytical data from coal chemistry (sheet 4 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V706 | V706 | V706 | V706 | V706 | V706 | V706 | V704 | V704 | V704 |
| Sample | L542 | L 543 | L 544 | L 545 | L 546 | L 547 | L 548 | 1 | 2 | 3 |
| Depth | 55.35 | 55.65 | 55.85 | 56.05 | 56.60 | 57.00 | 57.20 | 58.55 | 58.75 | 59.05 |
| Seam | F | F | F | F | F | F | F | F | F | F |
| Ply | F-5 | F-5 | F-4 | F-2 | F-2 | F-2 | F-1 | F-4 | F-3 | F-3 |
| Facies | III | III | IVa | IIb | IIb | IIb | Ib | IVa | III/II/I | Ia |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 50.58 | 52.02 | 18.95 | 58.62 | 59.65 | 55.73 | 41.6 | 33.95 | 54.07 | 60.25 |
| Ash (% db) | 39.42 | 36.19 | 26.94 | 15.51 | 13.55 | 13.57 | 16.5 | 57.85 | 28.18 | 12.42 |
| Volatile matter (% db) | 32.44 | 36.25 | 30.57 | 47.23 | 50.14 | 49.03 | 48.43 | 21.48 | 40.73 | 46.34 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | | 35.2 | | | 56.2 | | 55.22 | 29.58 | 43.31 | 56.32 |
| Hydrogen (% db) | | 2.55 | | | 4.02 | | 4.59 | 1.99 | 3.56 | 4.32 |
| Nitrogen (% db) | | | | | | | | *0.3* | *0.3* | *0.3* |
| Sulphur (% db) | 2.66 | 6.3 | 16.29 | 3.59 | 3.49 | 3.18 | 3.09 | 2.06 | 3.32 | 3.36 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | | | | | | | | 0.02 | 0.01 | 0.01 |
| Sulphate (% db) | | | | | | | | 0.07 | 0.13 | 0.1 |
| Organic (% db) | | | | | | | | 1.97 | 3.18 | 3.25 |
| HHV (MJ/kg db) | 15.05 | 13.03 | 15.78 | 21.43 | 22.19 | 22.28 | 22.85 | 10.66 | 18.02 | 21.81 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.02 | 12.38 | 45.81 | 1.02 | 3.1 | 0.05 | 0.1 | 0.131 | 0.216 | 0.107 |
| $Al_2O_3$ (% db) | 9.47 | 10.36 | 3.84 | 21.9 | 29.46 | 28.24 | 19.82 | 4.37 | 19.11 | 29.8 |
| $SiO_2$ (% db) | 76.8 | 61.1 | 43.9 | 28.8 | 27.1 | 29.9 | 41.1 | 84.5 | 64.8 | 27.9 |
| MgO (% db) | 3.74 | 3.84 | 1.16 | 12.3 | 11.52 | 11.76 | 9.39 | 1.98 | 5.56 | 11.86 |
| Ca0 (% db) | 2.92 | 2.54 | 1.09 | 8.32 | 9.15 | 6.32 | 7.65 | 1.95 | 5 | 10.6 |
| $K_2O$ (% db) | 0.06 | 0.08 | 0.15 | 0.15 | 0.16 | 0.08 | 0.12 | 0.051 | 0.131 | 0.216 |
| $Na_2O$ (% db) | 2.31 | 2.56 | 1.02 | 9 | 8.59 | 6.88 | 6.18 | 1.09 | 3.29 | 9.5 |
| $SO_3$ (% db) | 1.62 | 3.99 | 1.29 | 5.13 | 9.51 | 9.38 | 8.99 | 2.15 | 1.06 | 11.15 |
| $TiO_2$ (% db) | 3.82 | 3.74 | 2.25 | 1.32 | 0.15 | 1.52 | 4.87 | 2.6 | 1.56 | 0.55 |
| $SiO_2/Al_2O_3$ | 8.1 | 5.9 | 11.4 | 1.3 | 0.9 | 1.1 | 2.1 | 19.3 | 3.4 | 0.9 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.02 | 2.48 | 2.48 | 0.1 | 0.13 | 0.02 | 0.03 | 0.038 | 0.035 | 0.049 |
| Al (% db) | 1.09 | 1.29 | 0.19 | 1.07 | 1.15 | 1.06 | 0.9 | 1.01 | 2 | 1.28 |
| Si (% db) | 0.73 | 0.87 | | 0.6 | 0.71 | 0.72 | 0.61 | 0.55 | 1.18 | 0.66 |
| Mg (% db) | 0.89 | 0.82 | 0.11 | 1.17 | 0.91 | 0.95 | 0.86 | 0.61 | 0.98 | 0.84 |
| Ca (% db) | 0.81 | 0.64 | 0.14 | 0.96 | 0.87 | 0.91 | 0.83 | 0.68 | 1.02 | 0.87 |
| K (% db) | | | | | | | | 0.015 | 0.03 | 0.026 |
| Na (% db) | 0.68 | 0.67 | 0.16 | 1.09 | 0.86 | 0.84 | 0.72 | 0.38 | 0.75 | 0.87 |
| Cl (% db) | 0.39 | 0.41 | 0.14 | 0.7 | 0.54 | 0.51 | 0.44 | 0.11 | 0.26 | 0.34 |
| Assay quartz (% db) | | | | | | | | 46.54 | 13.64 | 0.52 |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 9.4 | 9.5 | 2.6 | 8.6 | 7.2 | 8.1 | 8.3 | 6.4 | 13.6 | 6.8 |
| Quartz (% db) | 25.9 | 17.7 | 10.6 | 0.5 | 0.3 | 0.3 | 2.9 | 45.9 | 11.9 | 0.3 |
| Quartz/kaolinite | 2.7 | 1.9 | 4.1 | 0.1 | 0.0 | 0.0 | 0.4 | 7.2 | 0.9 | 0.0 |

Appendix E2: Analytical data from coal chemistry (sheet 5 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 |
| Sample | 8 | 22 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| Depth | 61.20 | 69.50 | 72.85 | 59.20 | 59.80 | 60.25 | 60.75 | 63.15 | 63.70 | 64.40 |
| Seam | F | G | H | F | F | F | F | G | G | G |
| Ply | F-1 | G-1 | H-2 | F-2 | F-2 | F-2 | F-1 | G-5 | G-5 | G-4 |
| Facies | Ib | IIa | Ib | IIb | IIb | IIb | Ib | IIb | IIa | Ib |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 63.2 | 67.08 | 52.51 | 58.99 | 61.31 | 63.62 | 59.92 | 58.8 | 53.5 | 55.1 |
| Ash (% db) | 23.72 | 10.18 | 44.64 | 13.62 | 11.18 | 13.76 | 17.2 | 13.29 | 13.37 | 11.88 |
| Volatile matter (% db) | 39.6 | 47.51 | 32.76 | 47.35 | 45.98 | 45.59 | 47.15 | 44.92 | 49.79 | 51.98 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 55.75 | 58.61 | 38.14 | 56.81 | 59.89 | 58.47 | 55.5 | 57.18 | 58.05 | 59.94 |
| Hydrogen (% db) | 4.11 | 4.16 | 3.11 | 4.57 | 4.29 | 4.18 | 4.42 | 4.19 | 4.47 | 5.17 |
| Nitrogen (% db) | *0.3* | *0.3* | *0.3* | 0.3 | *0.3* | 0.3 | *0.3* | *0.3* | 0.4 | 0.3 |
| Sulphur (% db) | 2.83 | 2.79 | 1.75 | 3.01 | 2.95 | 2.95 | 3.02 | 2.94 | 3.19 | 2.85 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.17 | 0.08 |
| Sulphate (% db) | 0.14 | 0.14 | 0.05 | 0.1 | 0.11 | 0.11 | 0.08 | 0.09 | 0.3 | 0.12 |
| Organic (% db) | 2.68 | 2.64 | 1.69 | 2.9 | 2.83 | 2.83 | 2.93 | 2.84 | 2.72 | 2.65 |
| HHV (MJ/kg db) | 22.71 | 21.59 | 14.71 | 22.46 | 23.61 | 21.61 | 22.69 | 23.05 | 22.89 | 24.3 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.134 | 0.77 | 0.052 | 0.375 | 0.756 | 0.562 | 0.16 | 0.42 | 5.314 | 2.165 |
| $Al_2O_3$ (% db) | 10.32 | 16.4 | 1.88 | 25.95 | 26.57 | 24.82 | 13.9 | 28.31 | 23.43 | 20.45 |
| $SiO_2$ (% db) | 67.6 | 11.8 | 86.5 | 24.3 | 22.4 | 22.6 | 51.7 | 27.65 | 21.6 | 18.1 |
| MgO (% db) | 5.25 | 17.55 | 1.56 | 12.61 | 14.1 | 12.4 | 8.41 | 12.62 | 9.87 | 15.15 |
| Ca0 (% db) | 4.73 | 17.85 | 1.62 | 10.98 | 12.8 | 10.88 | 7.45 | 11.88 | 9.97 | 14.58 |
| $K_2O$ (% db) | 0.136 | 0.201 | 0.064 | 0.35 | 0.298 | 0.355 | 0.214 | 0.227 | 0.257 | 0.246 |
| $Na_2O$ (% db) | 4.25 | 7.65 | 0.89 | 9.98 | 9.6 | 11.52 | 5.9 | 8.05 | 6.12 | 8.58 |
| $SO_3$ (% db) | 6.43 | 29.43 | 4.32 | 14.69 | 15.64 | 16.57 | 9.9 | 12.21 | 21.19 | 20.12 |
| $TiO_2$ (% db) | 0.16 | 0.28 | 2.24 | 0.14 | 0.04 | 0.06 | 0.07 | 0.22 | 0.24 | 0.12 |
| $SiO_2/Al_2O_3$ | 6.6 | 0.7 | 46.0 | 0.9 | 0.8 | 0.9 | 3.7 | 1.0 | 0.9 | 0.9 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.04 | 0.023 | 0.024 | 0.083 | 0.061 | 0.084 | 0.064 | 0.056 | 0.253 | 0.058 |
| Al (% db) | 1.37 | 0.68 | 0.29 | 1.41 | 1.2 | 1.04 | 0.95 | 1.59 | 1.36 | 0.93 |
| Si (% db) | 0.71 | 0.16 | 0.07 | 0.76 | 0.56 | 0.45 | 0.44 | 0.97 | 0.8 | 0.49 |
| Mg (% db) | 0.86 | 0.94 | 0.49 | 1.03 | 0.8 | 0.9 | 0.94 | 0.97 | 1.01 | 1.08 |
| Ca (% db) | 0.88 | 1.07 | 0.63 | 1.06 | 0.85 | 0.94 | 0.98 | 1.08 | 1.16 | 1.26 |
| K (% db) | 0.027 | 0.029 | 0.014 | 0.026 | 0.032 | 0.033 | 0.028 | 0.03 | 0.03 | 0.026 |
| Na (% db) | 0.91 | 0.93 | 0.44 | 0.84 | 0.87 | 0.96 | 0.87 | 0.86 | 0.73 | 0.73 |
| Cl (% db) | 0.35 | 0.35 | 0.21 | 0.36 | 0.41 | 0.43 | 0.37 | 0.32 | 0.26 | 0.27 |
| Assay quartz (% db) | 13.4 | 0.25 | 34.69 | 0.14 | 0.15 | 0.36 | 6.04 | 0.07 | 0.43 | 0.35 |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 6.2 | 1.9 | 2.1 | 6.5 | 4.7 | 6.0 | 6.0 | 7.3 | 5.6 | 4.0 |
| Quartz (% db) | 13.2 | 0.3 | 37.6 | 0.3 | 0.3 | 0.3 | 6.1 | 0.3 | 0.3 | 0.3 |
| Quartz/kaolinite | 2.1 | 0.2 | 17.7 | 0.0 | 0.1 | 0.0 | 1.0 | 0.0 | 0.1 | 0.1 |

Appendix E2: Analytical data from coal chemistry (sheet 6 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 | V704 |
| Sample | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 |
| Depth | 64.80 | 65.55 | 65.95 | 66.40 | 67.10 | 67.65 | 68.20 | 68.65 | 69.35 | 69.65 |
| Seam | G | G | G | G | G | G | G | G | G | G |
| Ply | G-4 | G-4 | G-4 | G-4 | G-3 | G-3 | G-3 | G-2 | G-1 | G-1 |
| Facies | Ib | Ib | Ib | Ib | IIa | Ib | Ib | Ia | III | III |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 56.45 | 57.57 | 57.23 | 57.69 | 60.82 | 59.9 | 60.95 | 58.14 | 64.81 | 64.17 |
| Ash (% db) | 11.74 | 11.27 | 9.74 | 10.6 | 10.56 | 10.41 | 9 | 10.43 | 10.16 | 15.67 |
| Volatile matter (% db) | 52.3 | 51.24 | 55.5 | 52.57 | 49.91 | 51.67 | 49.43 | 53.63 | 47.74 | 45.09 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 59.97 | 59.29 | 62.07 | 60.32 | 59.65 | 60.33 | 62 | 61.01 | 60.46 | 57.17 |
| Hydrogen (% db) | 4.9 | 4.79 | 5.4 | 4.98 | 4.87 | 4.85 | 4.85 | 5.54 | 4.53 | 4.11 |
| Nitrogen (% db) | *0.3* | 0.3 | *0.3* | *0.3* | *0.3* | *0.3* | 0.2 | *0.3* | *0.3* | 0.3 |
| Sulphur (% db) | 2.93 | 2.85 | 2.61 | 2.82 | 2.83 | 2.81 | 2.85 | 2.79 | 3.06 | 3.04 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.05 | 0.04 | 0.01 | 0.1 | 0.05 | 0.03 | 0.05 | 0.01 | 0.04 | 0.14 |
| Sulphate (% db) | 0.34 | 0.12 | 0.06 | 0.1 | 0.13 | 0.2 | 0.12 | 0.09 | 0.28 | 0.17 |
| Organic (% db) | 2.54 | 2.69 | 2.54 | 2.62 | 2.65 | 2.58 | 2.68 | 2.69 | 2.74 | 2.73 |
| HHV (MJ/kg db) | 25.01 | 23.63 | 25.42 | 25.47 | 24.89 | 25.77 | 26.96 | 27.57 | 25.16 | 22.89 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 4.645 | 1.411 | 0.308 | 1.995 | 2.06 | 2.975 | 2.242 | 0.704 | 5.115 | 2.245 |
| $Al_2O_3$ (% db) | 18.85 | 19.39 | 18.6 | 18.47 | 18.45 | 17.4 | 13.2 | 19.55 | 14.6 | 14.5 |
| $SiO_2$ (% db) | 16.6 | 14.9 | 17.2 | 13.3 | 10.9 | 11 | 8.1 | 19.6 | 8 | 42 |
| MgO (% db) | 14.15 | 15.67 | 15.56 | 16.1 | 15.65 | 16.05 | 15.45 | 14.74 | 16.15 | 9.95 |
| Ca0 (% db) | 13.26 | 15.14 | 15.67 | 16.55 | 15.95 | 16.04 | 16.15 | 14.99 | 16.7 | 10.12 |
| $K_2O$ (% db) | 0.265 | 0.241 | 0.255 | 0.215 | 0.245 | 0.234 | 0.312 | 0.252 | 0.225 | 0.485 |
| $Na_2O$ (% db) | 8.74 | 10.04 | 10.75 | 9.62 | 10.58 | 10.06 | 11.62 | 9.66 | 10.25 | 7.25 |
| $SO_3$ (% db) | 22.19 | 23.5 | 20.63 | 25.34 | 24.72 | 24.86 | 30.76 | 20.65 | 28.19 | 11.63 |
| $TiO_2$ (% db) | 0.1 | 0.12 | 0.24 | 0.14 | 0.12 | 0.11 | 0.38 | 0.95 | 0.16 | 1.59 |
| $SiO_2/Al_2O_3$ | 0.9 | 0.8 | 0.9 | 0.7 | 0.6 | 0.6 | 0.6 | 1.0 | 0.5 | 2.9 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.383 | 0.039 | 0.024 | 0.054 | 0.069 | 0.139 | 0.08 | 0.049 | 0.248 | 0.116 |
| Al (% db) | 0.94 | 0.83 | 0.7 | 0.72 | 0.87 | 0.76 | 0.59 | 0.87 | 0.65 | 0.5 |
| Si (% db) | 0.46 | 0.34 | 0.29 | 0.27 | 0.28 | 0.24 | 0.1 | 0.42 | 0.1 | 0.13 |
| Mg (% db) | 0.99 | 1.03 | 0.95 | 0.99 | 0.96 | 1.02 | 0.82 | 0.92 | 0.96 | 0.93 |
| Ca (% db) | 1.12 | 1.24 | 1.16 | 1.23 | 1.19 | 1.25 | 1.03 | 1.16 | 1.26 | 1.16 |
| K (% db) | 0.027 | 0.025 | 0.026 | 0.025 | 0.026 | 0.026 | 0.026 | 0.028 | 0.029 | 0.031 |
| Na (% db) | 0.79 | 0.79 | 0.73 | 0.72 | 0.81 | 0.77 | 0.76 | 0.72 | 0.85 | 0.86 |
| Cl (% db) | 0.32 | 0.3 | 0.3 | 0.29 | 0.31 | 0.33 | 0.32 | 0.3 | 0.39 | 0.37 |
| Assay quartz (% db) | 0.2 | 0.26 | 0.43 | 0.23 | 0.18 | 0.46 | 0.28 | 0.31 | 0.24 | 3.57 |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 3.5 | 3.0 | 3.0 | 2.4 | 1.8 | 1.8 | 0.9 | 3.8 | 1.1 | 5.7 |
| Quartz (% db) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 3.9 |
| Quartz/kaolinite | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.3 | 0.1 | 0.3 | 0.7 |

Appendix E2: Analytical data from coal chemistry (sheet 7 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V704 | V704 | V672 | V672 | V672 | V672 | V672 | V672 | V672 | V672 |
| Sample | 44 | 45 | L 500 | L 501 | L 502 | L 503 | L 505 | L 506 | L 507 | L 508 |
| Depth | 72.25 | 72.70 | 34.90 | 35.40 | 37.00 | 37.65 | 38.10 | 38.50 | 38.90 | 39.15 |
| Seam | H | H | F | F | G | G | G | G | G | G |
| Ply | H-2 | H-2 | F-4 | F-2 | G-6 | G-6 | G-6 | G-5 | G-5 | G-4 |
| Facies | Ib | Ib | IVb | IIb | Ia | IIb | Ib | IIb | IIb | Ib |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 61.8 | 54.48 | 46.58 | 47.38 | 38.58 | 52.32 | 52.19 | 54.72 | 54.71 | 53.41 |
| Ash (% db) | 12.36 | 32.51 | 14.25 | 14.59 | 36.23 | 10.82 | 8.82 | 8.05 | 7.8 | 7.8 |
| Volatile matter (% db) | 48.98 | 41.12 | 52.13 | 49.35 | 37.87 | 49.57 | 51.87 | 47.42 | 49.14 | 51.25 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 60.05 | 46.99 | 58.44 | | 43.6 | | 62.61 | 62.98 | | |
| Hydrogen (% db) | 4.67 | 3.92 | 4.6 | | 3.31 | | 4.58 | 3.99 | | |
| Nitrogen (% db) | *0.3* | 0.3 | | | | | | | | |
| Sulphur (% db) | 2.91 | 2.05 | 2.48 | 2.71 | 2.58 | 2.69 | 2.07 | 2.24 | 2.24 | 2.09 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.01 | 0.01 | | | | | | | | |
| Sulphate (% db) | 0.09 | 0.06 | | | | | | | | |
| Organic (% db) | 2.81 | 1.98 | | | | | | | | |
| HHV (MJ/kg db) | 24.33 | 19.95 | 23.68 | 22.64 | 17.02 | 23.82 | 25.11 | 24.47 | 25.3 | 25.02 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.161 | 0.056 | 1.12 | 1.36 | 0.31 | 2.72 | 1.12 | 0.48 | 1.56 | 0.46 |
| $Al_2O_3$ (% db) | 14.52 | 2.92 | 20.85 | 19.64 | 3.31 | 7.55 | 7.52 | 7.9 | 6.3 | 6.18 |
| $SiO_2$ (% db) | 30.7 | 80.6 | 17.5 | 18.1 | 81.5 | 15.7 | 8.4 | 3.6 | 7.8 | 4 |
| MgO (% db) | 12.25 | 3.19 | 12.25 | 12.22 | 2.96 | 14.32 | 18.22 | 18.52 | 18.45 | 19.82 |
| Ca0 (% db) | 12.9 | 3.51 | 11.22 | 11.24 | 2.9 | 13.34 | 17.02 | 16.6 | 16.44 | 18.15 |
| $K_2O$ (% db) | 0.245 | 0.078 | 0.31 | 0.26 | 0.08 | 0.32 | 0.3 | 0.34 | 0.29 | 0.27 |
| $Na_2O$ (% db) | 8.24 | 2.41 | 8.95 | 8.75 | 2.68 | 12.78 | 13.58 | 14.72 | 14.1 | 13.3 |
| $SO_3$ (% db) | 19.64 | 4.88 | 21.9 | 22.25 | 5.55 | 31.66 | 32.86 | 36.36 | 34.94 | 35.86 |
| $TiO_2$ (% db) | 0.38 | 2.3 | 1.22 | 1.41 | 0.69 | 0.25 | 0.42 | 0.3 | 0.5 | 0.26 |
| $SiO_2/Al_2O_3$ | 2.1 | 27.6 | 0.8 | 0.9 | 24.6 | 2.1 | 1.1 | 0.5 | 1.2 | 0.6 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.044 | 0.037 | 0.1 | 0.15 | 0.07 | 0.05 | 0.06 | 0.02 | 0.04 | 0.02 |
| Al (% db) | 0.49 | 0.31 | 1.47 | 1.49 | 0.27 | 0.38 | 0.31 | 0.3 | 0.22 | 0.64 |
| Si (% db) | 0.12 | 0.04 | 0.01 | 0.3 | 0.04 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Mg (% db) | 0.92 | 0.56 | 1.03 | 1.06 | 0.62 | 0.85 | 0.91 | 0.75 | 0.77 | 0.9 |
| Ca (% db) | 1.22 | 0.79 | 1.17 | 1.2 | 0.69 | 0.94 | 1.04 | 0.94 | 0.87 | 1.01 |
| K (% db) | 0.024 | 0.017 | | | | | | | | |
| Na (% db) | 0.73 | 0.52 | 0.97 | 0.97 | 0.71 | 0.97 | 0.97 | 1.05 | 0.97 | 0.98 |
| Cl (% db) | 0.35 | 0.25 | 0.35 | 0.31 | 0.31 | 0.41 | 0.38 | 0.42 | 0.35 | 0.4 |
| Assay quartz (% db) | 2.02 | 24.3 | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 4.5 | 2.4 | 4.7 | 5.0 | 3.0 | 2.1 | 0.9 | 0.4 | 1.2 | 0.0 |
| Quartz (% db) | 1.7 | 25.1 | 0.3 | 0.3 | 28.1 | 0.7 | 0.3 | 0.3 | 0.0 | 0.3 |
| Quartz/kaolinite | 0.4 | 10.4 | 0.1 | 0.1 | 9.3 | 0.4 | 0.3 | 0.7 | 0.0 | 11.6 |

Appendix E2: Analytical data from coal chemistry (sheet 8 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V672 | V672 | V672 | V672 | V672 | V672 | V672 | V672 | V672 | V672 |
| Sample | L509 | L 510 | L 511 | L 512 | L 513 | L 514 | L 515 | L 516 | L 517 | L 518 |
| Depth | 39.50 | 39.85 | 40.30 | 40.75 | 41.25 | 41.75 | 42.05 | 42.20 | 42.70 | 43.00 |
| Seam | G | G | G | G | G | G | G | H | H | H |
| Ply | G-4 | G-4 | G-4 | G-4 | G-3 | G-2 | G-2 | H-1b | H-1b | H-1b |
| Facies | Ib | Ib | Ib | Ib | IIa | Ia | Ia | Ic | Ia | Ia |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 41.19 | 52.56 | 56.53 | 54.21 | 54.72 | 56.84 | 55.03 | 50.04 | 50.48 | 51.65 |
| Ash (% db) | 7.78 | 8.14 | 7.95 | 7.1 | 7.48 | 7.1 | 8.06 | 8 | 15.94 | 26.27 |
| Volatile matter (% db) | 50.89 | 52.76 | 49.66 | 52.82 | 47.5 | 50.73 | 54.05 | 59.18 | 50.94 | 40.26 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 62.41 | 62.99 | 62.7 | | | | | 64.94 | | |
| Hydrogen (% db) | 4.44 | 4.6 | 4.27 | | | | | 5.8 | | |
| Nitrogen (% db) | | | | | | | | | | |
| Sulphur (% db) | 2.24 | 2.14 | 2.21 | 2.1 | 2.17 | 2.1 | 2.02 | 1.87 | 1.86 | 1.8 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | | | | | | | | | | |
| Sulphate (% db) | | | | | | | | | | |
| Organic (% db) | | | | | | | | | | |
| HHV (MJ/kg db) | 24.78 | 25.67 | 24.47 | 25.33 | 24.05 | 25.04 | 26.13 | 27.78 | 23.69 | 20.21 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.17 | 0.42 | 0.1 | 1.15 | 0.23 | 0.38 | 0.36 | 0.29 | 0.22 | 1.45 |
| $Al_2O_3$ (% db) | 6.45 | 5.74 | 6.35 | 5.44 | 6.01 | 5.25 | 4.25 | 3.07 | 1.61 | 1.04 |
| $SiO_2$ (% db) | 2.5 | 5.3 | 1.5 | 2 | 1 | 2.5 | 19.2 | 26.8 | 56.2 | 76.6 |
| MgO (% db) | 22 | 22.01 | 22.71 | 21.9 | 20.78 | 21.75 | 18.74 | 15.55 | 6.69 | 4.02 |
| Ca0 (% db) | 20.1 | 19.55 | 20.41 | 19.92 | 17.75 | 18.9 | 17.46 | 14.76 | 6.18 | 3.95 |
| $K_2O$ (% db) | 0.24 | 0.23 | 0.22 | 0.23 | 0.29 | 0.25 | 0.2 | 0.2 | 0.18 | 0.11 |
| $Na_2O$ (% db) | 11.94 | 13.36 | 10.72 | 11.84 | 14.42 | 13.65 | 12.32 | 12.37 | 7.43 | 3.7 |
| $SO_3$ (% db) | 35.46 | 32.8 | 36.36 | 34.3 | 38.21 | 36.28 | 23.85 | 23.4 | 15.12 | 4.43 |
| $TiO_2$ (% db) | 0.15 | 0.22 | 0.16 | 0.18 | 0.12 | 0.25 | 1.25 | 2.12 | 3.14 | 1.24 |
| $SiO_2/Al_2O_3$ | 0.4 | 0.9 | 0.2 | 0.4 | 0.2 | 0.5 | 4.5 | 8.7 | 34.9 | 73.7 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.02 | 0.02 | 0.02 | 0.05 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.24 |
| Al (% db) | 0.24 | 0.2 | 0.23 | 0.18 | 0.2 | 0.16 | 0.14 | 0.1 | 0.12 | 0.12 |
| Si (% db) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Mg (% db) | 0.95 | 0.92 | 0.95 | 0.85 | 0.82 | 0.76 | 0.75 | 0.65 | 0.65 | 0.56 |
| Ca (% db) | 1.07 | 1 | 1.04 | 0.95 | 0.9 | 0.84 | 0.84 | 0.76 | 0.73 | 0.64 |
| K (% db) | | | | | | | | | | |
| Na (% db) | 0.99 | 1.06 | 1.01 | 0.96 | 1.09 | 1.02 | 0.92 | 0.83 | 0.82 | 0.79 |
| Cl (% db) | 0.45 | 0.5 | 0.44 | 0.49 | 0.42 | 0.41 | 0.42 | 0.43 | 0.42 | 0.38 |
| Assay quartz (% db) | | | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 0.2 | 0.3 | 0.0 | 0.1 | 0.1 | 0.2 | 0.9 | 0.6 | 0.6 | 0.7 |
| Quartz (% db) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 1.1 | 1.9 | 8.7 | 19.8 |
| Quartz/kaolinite | 1.5 | 1.1 | 7.2 | 3.3 | 5.6 | 1.8 | 1.3 | 3.0 | 13.3 | 28.7 |

Appendix E2: Analytical data from coal chemistry (sheet 9 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | S12 | S12 | S12 | S12 | S12 | S12 | S12 | S12 | S12 | S12 |
| Sample | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 |
| Depth | 0.30 | 0.70 | 1.00 | 1.50 | 1.90 | 2.25 | 2.65 | 3.10 | 3.50 | 3.95 |
| Seam | G | G | G | G | G | G | G | G | G | G |
| Ply | G-6 | G-6 | G-6 | G-5 | G-5 | G-4 | G-4 | G-4 | G-4 | G-4 |
| Facies | Ia | Ia | Ia | IIa | IIa | Ib | Ib | Ib | Ib | Ib |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 61.03 | 58.94 | 60.96 | 61.15 | 60.06 | 60.81 | 60.88 | 62.54 | 62.23 | 65.66 |
| Ash (% db) | 14.55 | 13.88 | 12.29 | 12.08 | 12.62 | 9.95 | 9.58 | 8.8 | 8.43 | 7.8 |
| Volatile matter (% db) | 48.71 | 48.95 | 49.51 | 47.57 | 48.49 | 51.11 | 50.28 | 50.17 | 52.21 | 48.05 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 55.81 | 56.69 | 58.57 | 58.85 | 59.94 | 60.74 | 60.68 | 61.85 | 62.75 | 62.07 |
| Hydrogen (% db) | 4.17 | 4.4 | 4.29 | 4.19 | 4.44 | 4.21 | 4.24 | 4.52 | 4.75 | 4.32 |
| Nitrogen (% db) | | | | | | | | | | |
| Sulphur (% db) | 3.73 | 4.14 | 3.38 | 3.46 | 4.27 | 3.33 | 3.15 | 3.14 | 3.15 | 2.9 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.23 | 0.5 | 0.16 | 0.31 | 1.18 | 0.27 | 0.02 | 0.02 | 0.02 | 0.01 |
| Sulphate (% db) | 0.15 | 0.11 | 0.09 | 0.11 | 0.08 | 0.16 | 0.08 | 0.07 | 0.07 | 0.08 |
| Organic (% db) | 3.35 | 3.53 | 3.13 | 3.04 | 3.01 | 2.9 | 3.05 | 3.05 | 3.06 | 2.82 |
| HHV (MJ/kg db) | 21.06 | 21.35 | 22.04 | 21.78 | 22.59 | 22.88 | 22.48 | 23.06 | 23.88 | 22.88 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 2.95 | 5.86 | 1.98 | 4.22 | 13.5 | 5.26 | 0.37 | 0.44 | 0.64 | 3.1 |
| $Al_2O_3$ (% db) | 19.58 | 17.43 | 17.56 | 14.13 | 11.29 | 10.75 | 8.14 | 6.78 | 4.82 | 4.2 |
| $SiO_2$ (% db) | 24.55 | 19.5 | 16.6 | 13.95 | 10.2 | 3.65 | 2.35 | 2.65 | 3.15 | 1.25 |
| MgO (% db) | 9.75 | 10.3 | 12.28 | 12.62 | 11.4 | 13.7 | 15.14 | 15.93 | 16.17 | 15.12 |
| Ca0 (% db) | 12.16 | 12.8 | 15.06 | 15.55 | 14.31 | 17.02 | 19.26 | 19.76 | 20.14 | 17.82 |
| $K_2O$ (% db) | 0.25 | 0.21 | 0.3 | 0.28 | 0.22 | 0.26 | 0.25 | 0.27 | 0.26 | 0.31 |
| $Na_2O$ (% db) | 8.84 | 8.5 | 10.16 | 10.59 | 9.57 | 12.06 | 12.38 | 13.3 | 12.84 | 15.55 |
| $SO_3$ (% db) | 20.42 | 23.45 | 24.04 | 27.33 | 29.31 | 34.55 | 39.54 | 39.88 | 39.61 | 40.4 |
| $TiO_2$ (% db) | 0.55 | 0.73 | 0.37 | 0.23 | 0.18 | 0.1 | 0.13 | 0.23 | 0.27 | 0.2 |
| $SiO_2/Al_2O_3$ | 1.3 | 1.1 | 0.9 | 1.0 | 0.9 | 0.3 | 0.3 | 0.4 | 0.7 | 0.3 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.1 | 0.09 | 0.03 | 0.07 | 0.08 | 0.12 | 0.03 | 0.01 | 0.01 | 0.18 |
| Al (% db) | 0.57 | 0.6 | 0.54 | 0.44 | 0.35 | 0.42 | 0.39 | 0.29 | 0.19 | 0.17 |
| Si (% db) | 0.26 | 0.27 | 0.27 | 0.18 | 0.07 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 |
| Mg (% db) | 0.86 | 0.85 | 0.89 | 0.91 | 0.83 | 0.8 | 0.9 | 0.81 | 0.8 | 0.68 |
| Ca (% db) | 1.28 | 1.29 | 1.34 | 1.36 | 1.26 | 1.22 | 1.34 | 1.21 | 1.2 | 0.98 |
| K (% db) | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Na (% db) | 0.9 | 0.86 | 0.89 | 0.88 | 0.84 | 0.86 | 0.92 | 0.89 | 0.87 | 0.96 |
| Cl (% db) | 0.54 | 0.48 | 0.54 | 0.54 | 0.51 | 0.49 | 0.55 | 0.51 | 0.52 | 0.56 |
| Assay quartz (% db) | | | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 7.2 | 5.2 | 3.7 | 3.0 | 2.1 | 0.1 | 0.3 | 0.3 | 0.4 | 0.0 |
| Quartz (% db) | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Quartz/kaolinite | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 2.2 | 1.1 | 1.0 | 0.8 | 18.6 |

Appendix E2: Analytical data from coal chemistry (sheet 10 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | S12 | S12 | S12 | S12 | S12 | V675 | V690 | V690 | V672 | V690 |
| Sample | 111 | 112 | 113 | 114 | 115 | L153 | L 154 | L155 | L365 | L367 |
| Depth | 4.65 | 5.05 | 5.40 | 5.85 | 6.15 | 30.60 | 45.10 | 45.20 | 34.00 | 53.30 |
| Seam | G | G | G | G | Floor | G | F | F | G | G |
| Ply | G-3 | G-3 | G-2 | G-1 | | G-5 | F-5 | F-4 | F-? | G-2 |
| Facies | IIa | IIa | Ia | III | | IV | III | IVa | IVb | Ia |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 63.07 | 62.49 | 62.86 | 60.97 | 44.54 | 51.98 | 64.56 | 43.58 | 54.96 | 61.22 |
| Ash (% db) | 8.77 | 10.97 | 12.86 | 17.3 | 54.45 | 8.74 | 16.26 | 48.81 | 13.87 | 11.13 |
| Volatile matter (% db) | 50.58 | 51.4 | 50 | 48.59 | 28.14 | 39.41 | 45.64 | 22.50 | 52.41 | 50.62 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 62.04 | 60.72 | 59.61 | 57.12 | 32.13 | 65.71 | | 34.26 | | |
| Hydrogen (% db) | 4.67 | 4.56 | 4.72 | 4.62 | 2.81 | 3.26 | | 1.77 | | |
| Nitrogen (% db) | | | | | | 0.70 | | | | |
| Sulphur (% db) | 3.45 | 3.08 | 2.92 | 2.69 | 1.28 | 2.21 | 4.13 | 1.89 | 2.50 | 2.83 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.25 | 0.14 | 0.06 | 0.23 | 0.06 | | | | | |
| Sulphate (% db) | 0.11 | 0.1 | 0.06 | 0.07 | 0.03 | | | | | |
| Organic (% db) | 3.09 | 2.84 | 2.8 | 2.39 | 1.19 | | | | | |
| HHV (MJ/kg db) | 23.5 | 23.4 | 24.16 | 23.28 | 13.47 | 25.52 | 21.52 | 13.09 | 23.69 | 24.34 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 4.55 | 1.95 | 0.95 | 2.71 | 1.25 | 10.02 | 0.60 | 0.10 | 1.00 | 0.12 |
| $Al_2O_3$ (% db) | 2.94 | 1.84 | 1.51 | 1.06 | 0.17 | 9.68 | 23.76 | 4.85 | 22.92 | 15.75 |
| $SiO_2$ (% db) | 2.2 | 25.95 | 44.4 | 55.45 | 92.7 | 57.40 | 26.70 | 83.10 | 17.90 | 23.40 |
| MgO (% db) | 15.72 | 11.7 | 9.43 | 6.73 | 1.02 | 3.92 | 12.20 | 1.58 | 13.16 | 13.65 |
| Ca0 (% db) | 19.7 | 14.85 | 11.89 | 8.67 | 1.34 | 3.30 | 12.21 | 1.76 | 12.55 | 14.85 |
| $K_2O$ (% db) | 0.23 | 0.22 | 0.16 | 0.13 | 0.3 | 0.40 | 0.15 | 0.07 | 0.22 | 0.17 |
| $Na_2O$ (% db) | 12.35 | 10.11 | 7.96 | 5.68 | 0.96 | 6.74 | 7.25 | 1.21 | 8.85 | 7.95 |
| $SO_3$ (% db) | 40.26 | 28.6 | 17.68 | 15.56 | 2.83 | 5.91 | 11.76 | 1.52 | 17.81 | 19.89 |
| $TiO_2$ (% db) | 0.26 | 3.71 | 5.21 | 3 | 0.32 | 1.19 | 1.76 | 5.37 | 1.50 | 2.12 |
| $SiO_2/Al_2O_3$ | 0.7 | 14.1 | 29.4 | 52.3 | 545.3 | 5.9 | 1.1 | 17.1 | 0.8 | 1.5 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.05 | 0.03 | 0.03 | 0.14 | 0.47 | 0.29 | 0.08 | 0.04 | 0.10 | 0.02 |
| Al (% db) | 0.13 | 0.1 | 0.08 | 0.07 | 0.04 | 0.11 | 1.51 | 0.49 | 1.45 | 0.36 |
| Si (% db) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.20 | 1.05 | 0.24 | 0.31 | 0.06 |
| Mg (% db) | 0.83 | 0.79 | 0.71 | 0.71 | 0.32 | 0.13 | 1.08 | 0.45 | 0.97 | 0.82 |
| Ca (% db) | 1.21 | 1.15 | 1.03 | 1.04 | 0.48 | 0.16 | 1.26 | 0.58 | 1.09 | 1.05 |
| K (% db) | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | | | | | |
| Na (% db) | 0.87 | 0.86 | 0.81 | 0.74 | 0.37 | 0.41 | 0.95 | 0.36 | 0.94 | 0.72 |
| Cl (% db) | 0.48 | 0.49 | 0.48 | 0.44 | 0.23 | 0.33 | 0.57 | 0.23 | 0.34 | 0.43 |
| Assay quartz (% db) | | | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 0.2 | 0.5 | 0.5 | 0.5 | 0.2 | 2.1 | 8.7 | 6.0 | 4.7 | 4.4 |
| Quartz (% db) | 0.3 | 2.6 | 5.5 | 9.4 | 50.4 | 4.0 | 0.3 | 37.8 | 0.3 | 0.5 |
| Quartz/kaolinite | 1.5 | 5.1 | 11.2 | 20.2 | 215.2 | 1.9 | 0.0 | 6.3 | 0.1 | 0.1 |

Appendix E2: Analytical data from coal chemistry (sheet 11 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V690 | V701 | V701 | V703 | V707 | V723 | V723 | V723 | S12 | V674 |
| Sample | L369 | L377 | L378 | L380 | L385 | L388 | L389 | L390 | L410 | L530 |
| Depth | 57.60 | 51.40 | 52.80 | 63.00 | 56.90 | 36.60 | 38.00 | 38.60 | TL1 | 30.95 |
| Seam | H | F | F | G | G | F | G | G | - | G |
| Ply | H-1b | F-5 | F-5 | G-2 | G-6 | F-2 | G-6 | G-5 | TL1 | G-3 |
| Facies | Ia | III | III | Ib | Ic | IVb | IVb | IVb | - | IIa |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 81.89 | 51.25 | 57.65 | 58.29 | 49.78 | 53.99 | 52.45 | 54.64 | 58.13 | 56.03 |
| Ash (% db) | 11.69 | 38.43 | 23.30 | 8.56 | 10.64 | 23.76 | 17.05 | 14.04 | 41.12 | 11.47 |
| Volatile matter (% db) | 43.16 | 41.05 | 43.24 | 57.86 | 62.27 | 43.34 | 46.02 | 49.84 | 32.92 | 50.32 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 58.03 | | | | 63.33 | 47.68 | 54.61 | 57.78 | 34.34 | |
| Hydrogen (% db) | 4.09 | | | | 6.25 | 3.47 | 4.00 | 3.93 | 2.14 | |
| Nitrogen (% db) | 0.50 | | | | | | | | | |
| Sulphur (% db) | 2.64 | 3.39 | 3.30 | 2.28 | 2.68 | 3.42 | 3.29 | 2.94 | 5.35 | 2.97 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | | | | | | | | | | |
| Sulphate (% db) | | | | | | | | | | |
| Organic (% db) | | | | | | | | | | |
| HHV (MJ/kg db) | 22.77 | 17.72 | 20.33 | 27.14 | 27.39 | 18.02 | 21.16 | 22.36 | 13.03 | 24.54 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 1.02 | 3.48 | 0.59 | 0.58 | 0.68 | 6.73 | 1.77 | 1.76 | 9.67 | 0.34 |
| $Al_2O_3$ (% db) | 6.95 | 6.06 | 15.25 | 12.36 | 20.50 | 28.05 | 30.15 | 25.87 | 12.04 | 7.40 |
| $SiO_2$ (% db) | 44.60 | 80.20 | 59.00 | 15.50 | 32.70 | 29.10 | 24.00 | 17.60 | 60.90 | 31.60 |
| MgO (% db) | 8.73 | 2.20 | 6.30 | 15.32 | 12.10 | 7.92 | 11.40 | 12.22 | 3.59 | 12.62 |
| Ca0 (% db) | 8.85 | 1.82 | 5.00 | 18.56 | 9.34 | 8.95 | 12.14 | 13.70 | 3.60 | 14.18 |
| $K_2O$ (% db) | 0.35 | 0.07 | 0.10 | 0.18 | 0.20 | 0.14 | 0.22 | 0.20 | 0.58 | 0.03 |
| $Na_2O$ (% db) | 10.55 | 2.51 | 6.04 | 8.48 | 8.17 | 5.31 | 7.10 | 7.32 | 4.83 | 9.69 |
| $SO_3$ (% db) | 16.55 | 1.01 | 3.60 | 25.57 | 13.93 | 8.18 | 11.71 | 17.12 | 5.59 | 20.34 |
| $TiO_2$ (% db) | 1.10 | 3.36 | 2.84 | 0.72 | 0.68 | 0.82 | 0.18 | 0.30 | 0.79 | 2.82 |
| $SiO_2/Al_2O_3$ | 6.4 | 13.2 | 3.9 | 1.3 | 1.6 | 1.0 | 0.8 | 0.7 | 5.1 | 4.3 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.08 | 0.73 | 0.07 | 0.04 | 0.05 | 0.95 | 0.15 | 0.14 | 1.86 | 0.02 |
| Al (% db) | 0.47 | 0.81 | 0.88 | 0.31 | 0.37 | 2.19 | 1.30 | 1.04 | 0.38 | 0.39 |
| Si (% db) | 0.09 | 0.40 | | 0.03 | 0.19 | 0.89 | 0.58 | 0.23 | 0.34 | 0.01 |
| Mg (% db) | 0.61 | 0.47 | 0.84 | 0.71 | 0.73 | 1.08 | 1.05 | 0.94 | 0.88 | 0.81 |
| Ca (% db) | 0.75 | 0.51 | 0.78 | 1.01 | 0.67 | 1.52 | 1.33 | 1.24 | 1.08 | 1.05 |
| K (% db) | | | | | | | | | | |
| Na (% db) | 1.25 | 0.67 | 1.07 | 0.67 | 0.65 | 0.85 | 0.78 | 0.78 | 1.39 | 0.91 |
| Cl (% db) | 1.28 | 0.40 | 0.54 | 0.36 | 0.41 | 0.34 | 0.27 | 0.21 | 1.06 | 0.51 |
| Assay quartz (% db) | | | | | | | | | | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 2.1 | 5.9 | 9.0 | 2.7 | 5.5 | 14.2 | 8.2 | 4.7 | 12.5 | 2.1 |
| Quartz (% db) | 4.3 | 28.1 | 9.6 | 0.1 | 0.9 | 0.3 | 0.3 | 0.3 | 19.2 | 2.6 |
| Quartz/kaolinite | 2.1 | 4.8 | 1.1 | 0.0 | 0.2 | 0.0 | 0.0 | 0.1 | 1.5 | 1.2 |

Appendix E2: Analytical data from coal chemistry (sheet 12 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | V674 | V674 | V674 | V674 | V674 | B28 | B28 | B28 | B28 | B28 |
| Sample | L531 | L532 | L533 | L534 | L535 | 2 | 3 | 4 | 6 | 7 |
| Depth | 31.35 | 31.55 | 31.95 | 32.40 | 32.70 | 63.05 | 63.40 | 63.80 | 64.30 | 64.40 |
| Seam | G | G | G | G | G | B1 | B1 | B1 | B1 | B1 |
| Ply | G-3 | G-3 | G-1 | G-1 | G-1 | B2-4 | B1-4 | B1-4 | B1-4 | B1-4 |
| Facies | IIa | III | III | III | III | Ia | Ia | Ib | Ib | IIa |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 59.12 | 60.35 | 61.72 | 59.56 | 63.35 | 42.46 | 60.36 | 50.83 | 50.25 | 50.77 |
| Ash (% db) | 9.35 | 7.86 | 9.24 | 12.21 | 12.71 | 18.60 | 3.48 | 13.06 | 17.09 | 15.91 |
| Volatile matter (% db) | 49.29 | 54.13 | 52.53 | 50.28 | 48.41 | 51.19 | 65.37 | 47.66 | 53.38 | 47.81 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | | | | 58.28 | 57.55 | | | 55.22 | 56.57 | |
| Hydrogen (% db) | | | | 4.33 | 4.62 | | | 4.37 | 5.30 | |
| Nitrogen (% db) | | | | | 0.50 | | | 0.50 | 0.30 | |
| Sulphur (% db) | 3.00 | 3.07 | 2.73 | 3.11 | 3.38 | 4.67 | 3.41 | 4.96 | 4.63 | 4.82 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | | | | | | 0.13 | 0.02 | 0.16 | 0.06 | 0.25 |
| Sulphate (% db) | | | | | | 0.47 | 0.33 | 0.26 | 0.25 | 0.42 |
| Organic (% db) | | | | | | | 3.06 | 4.54 | 4.32 | 4.15 |
| HHV (MJ/kg db) | 24.51 | 24.08 | 25.65 | 24.23 | 23.79 | 22.26 | 25.3 | 22.76 | 24.23 | 22.51 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.36 | 0.37 | 0.18 | 3.25 | 2.50 | 1.97 | 1.36 | 3.23 | 1.50 | 4.06 |
| $Al_2O_3$ (% db) | 10.35 | 12.16 | 8.74 | 6.36 | 5.62 | 9.29 | 5.56 | 13.83 | 9.59 | 14.83 |
| $SiO_2$ (% db) | 11.70 | 1.70 | 23.60 | 30.80 | 32.40 | 62.50 | 8.7 | 39.50 | 61.50 | 44.20 |
| MgO (% db) | 15.90 | 18.77 | 14.56 | 9.92 | 10.80 | 5.10 | 12.68 | 9.00 | 5.30 | 7.70 |
| Ca0 (% db) | 17.79 | 20.25 | 15.92 | 10.94 | 11.62 | 4.04 | 5.81 | 6.71 | 4.15 | 5.81 |
| $K_2O$ (% db) | 0.22 | 0.18 | 0.22 | 0.23 | 0.21 | 0.77 | 0.28 | 0.26 | 0.22 | 0.24 |
| $Na_2O$ (% db) | 10.80 | 9.20 | 10.02 | 9.41 | 9.12 | 6.62 | 24.88 | 10.71 | 7.65 | 10.71 |
| $SO_3$ (% db) | 30.29 | 33.33 | 21.12 | 23.06 | 22.54 | 8.63 | 39.05 | 16.79 | 9.54 | 11.74 |
| $TiO_2$ (% db) | 2.02 | 1.40 | 3.49 | 3.88 | 4.02 | 0.84 | 0.41 | 0.35 | 0.21 | 0.33 |
| $SiO_2/Al_2O_3$ | 1.1 | 0.1 | 2.7 | 4.8 | 5.8 | 6.7 | 1.6 | 2.9 | 6.4 | 3.0 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.01 | 0.02 | 0.02 | 0.27 | 0.21 | 0.12 | 0.04 | 0.10 | 0.15 | 0.24 |
| Al (% db) | 0.45 | 0.48 | 0.38 | 0.38 | 0.35 | 0.67 | 0.09 | 0.50 | 0.47 | 0.58 |
| Si (% db) | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.13 | | 0.21 | 0.25 | 0.29 |
| Mg (% db) | 0.86 | 0.90 | 0.75 | 0.75 | 0.89 | 0.55 | 0.32 | 0.69 | 0.63 | 0.72 |
| Ca (% db) | 1.11 | 1.21 | 0.99 | 1.00 | 1.14 | 0.51 | 0.18 | 0.62 | 0.47 | 0.66 |
| K (% db) | | | | | | 0.17 | | 0.04 | 0.03 | 0.04 |
| Na (% db) | 0.96 | 1.05 | 0.93 | 0.90 | 1.05 | 1.07 | 1.54 | 1.35 | 1.40 | 1.40 |
| Cl (% db) | 0.51 | 0.52 | 0.57 | 0.51 | 0.59 | 0.88 | 2.24 | 1.19 | 1.28 | 1.38 |
| Assay quartz (% db) | | | | | | 10.16 | | 2.77 | 8.10 | 4.38 |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 1.7 | 0.1 | 2.0 | 2.0 | 1.8 | 4.4 | 0.5 | 4.6 | 4.1 | 6.0 |
| Quartz (% db) | 0.3 | 0.3 | 1.2 | 2.8 | 3.3 | 9.6 | 0.1 | 3.0 | 8.6 | 4.3 |
| Quartz/kaolinite | 0.2 | 4.2 | 0.6 | 1.4 | 1.8 | 2.2 | 0.2 | 0.7 | 2.1 | 0.7 |

Appendix E2: Analytical data from coal chemistry (sheet 13 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Depth | 64.80 | 65.30 | 65.70 | 66.15 | 66.50 | 67.00 | 67.40 | 68.00 | 68.50 | 69.00 |
| Seam | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 |
| Ply | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 | B1-3 |
| Facies | IIa | IIa | IIa | IIa | IIa | Ic | IIa | IIa | IIa | IIa |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 54.28 | 54.23 | 55.22 | 54.94 | 52.33 | 50.91 | 54.26 | 52.41 | 52.39 | 54.37 |
| Ash (% db) | 8.40 | 8.86 | 8.48 | 9.88 | 11.56 | 8.98 | 8.77 | 7.58 | 9.13 | 12.71 |
| Volatile matter (% db) | 49.11 | 48.9 | 47.10 | 48.45 | 48.05 | 52.6 | 48.75 | 48.47 | 49.80 | 47.77 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | | 59.19 | | | | 60.65 | | 60.65 | 59.05 | |
| Hydrogen (% db) | | 4.24 | | | | 4.74 | | 4.02 | 4.08 | |
| Nitrogen (% db) | | 0.5 | | | | | | | 0.50 | |
| Sulphur (% db) | 5.22 | 5.25 | 5.18 | 5.05 | 5.30 | 4.68 | 4.94 | 4.97 | 5.14 | 4.53 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.01 | 0.02 | 0.01 | 0.01 | 0.19 | 0.01 | 0.05 | 0.01 | 0.14 | 0.02 |
| Sulphate (% db) | 0.20 | 0.26 | 0.22 | 0.24 | 0.36 | 0.22 | 0.31 | 0.26 | 0.34 | 0.36 |
| Organic (% db) | 5.01 | 4.97 | 4.95 | 4.80 | 4.75 | 4.45 | 4.58 | 4.70 | 4.66 | 4.15 |
| HHV (MJ/kg db) | 24.20 | 23.45 | 23.84 | 22.97 | 22.85 | 25.41 | 23.55 | 24.57 | 23.56 | 23.59 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.50 | 0.75 | 0.46 | 0.14 | 5.75 | 0.1 | 0.34 | 0.26 | 5.99 | 2.93 |
| $Al_2O_3$ (% db) | 10.90 | 6.43 | 10.15 | 16.24 | 17.72 | 12.78 | 11.65 | 9.45 | 15.26 | 21.14 |
| $SiO_2$ (% db) | 10.80 | 3.15 | 7.40 | 15.4 | 19.60 | 30.1 | 11.70 | 2.7 | 13.50 | 24.9 |
| MgO (% db) | 17.82 | 15.05 | 16.47 | 13.2 | 9.46 | 13.55 | 15.50 | 22.22 | 13.01 | 10.52 |
| Ca0 (% db) | 12.31 | 10.61 | 11.37 | 8.97 | 6.48 | 9.22 | 10.60 | 13.57 | 8.89 | 7.14 |
| $K_2O$ (% db) | 0.25 | 0.31 | 0.26 | 0.23 | 0.30 | 0.18 | 0.27 | 0.2 | 0.27 | 0.25 |
| $Na_2O$ (% db) | 15.65 | 22.02 | 19.10 | 19.27 | 16.45 | 14.58 | 17.85 | 15.95 | 15.66 | 14.02 |
| $SO_3$ (% db) | 33.27 | 38.83 | 33.03 | 25.49 | 23.40 | 18 | 30.96 | 33.45 | 26.01 | 17.85 |
| $TiO_2$ (% db) | 0.18 | 0.01 | 0.13 | 0.1 | 0.00 | 0.16 | 0.00 | 0.14 | 0.00 | 0.18 |
| $SiO_2/Al_2O_3$ | 1.0 | 0.5 | 0.7 | 0.9 | 1.1 | 2.4 | 1.0 | 0.3 | 0.9 | 1.2 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.01 | 0.03 | 0.02 | 0.01 | 0.29 | 0.02 | 0.02 | 0.02 | 0.22 | 0.21 |
| Al (% db) | 0.40 | 0.27 | 0.38 | 0.27 | 0.64 | 0.26 | 0.40 | 0.25 | 0.53 | 0.35 |
| Si (% db) | 0.07 | 0.01 | 0.07 | 0.05 | 0.38 | 0.08 | 0.11 | 0.01 | 0.25 | 0.16 |
| Mg (% db) | 0.75 | 0.78 | 0.77 | 0.73 | 0.68 | 0.64 | 0.78 | 0.72 | 0.64 | 0.71 |
| Ca (% db) | 0.66 | 0.65 | 0.65 | 0.59 | 0.56 | 0.53 | 0.66 | 0.59 | 0.53 | 0.57 |
| K (% db) | 0.04 | 0.03 | 0.04 | 0.03 | 0.03 | | 0.04 | | 0.04 | |
| Na (% db) | 1.64 | 1.61 | 1.60 | 1.57 | 1.40 | 1.36 | 1.49 | 1.51 | 1.37 | 1.4 |
| Cl (% db) | 1.40 | 1.43 | 1.44 | 1.52 | 1.25 | 1.41 | 1.32 | 1.36 | 1.18 | 1.23 |
| Assay quartz (% db) | 0.27 | | 0.18 | | 0.24 | | 0.36 | | 0.12 | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 1.3 | 0.4 | 0.7 | 2.6 | 4.2 | 2.9 | 1.8 | 0.0 | 2.2 | 6.8 |
| Quartz (% db) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 1.4 | 0.2 | 0.2 | 0.2 | 0.0 |
| Quartz/kaolinite | 0.2 | 0.5 | 0.3 | 0.1 | 0.0 | 0.5 | 0.1 | 20.0 | 0.1 | 0.0 |

Appendix E2: Analytical data from coal chemistry (sheet 14 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 18 | 19 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| Depth | 69.45 | 70.10 | 70.45 | 71.00 | 71.40 | 72.00 | 72.40 | 72.90 | 73.60 | 74.20 |
| Seam | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 | B1 |
| Ply | B1-3 | B1-3 | B1-3 | B1-3 | B1-2 | B1-2 | B1-2 | B1-2 | B1-1 | B1-1 |
| Facies | IIa | IIa | IIa | IIa | Ia | Ia | Ia | Ia | Ia | Ib |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 54.28 | 53.95 | 54.49 | 52.1 | 51.76 | 53.12 | 54.44 | 52.02 | 52.14 | 55.05 |
| Ash (% db) | 10.51 | 7.88 | 7.39 | 8.26 | 8.13 | 8.72 | 10.7 | 7.86 | 9.08 | 8.94 |
| Volatile matter (% db) | 47.46 | 48.32 | 49.48 | 48.93 | 52.50 | 51.40 | 48.45 | 51.63 | 49.87 | 49.62 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | | 61.16 | | 60.73 | 60.20 | | | 61.98 | | |
| Hydrogen (% db) | | 4.32 | | 4.18 | 4.77 | | | 4.76 | | |
| Nitrogen (% db) | | | | 0.5 | 0.30 | | | 0.50 | | |
| Sulphur (% db) | 4.65 | 4.79 | 4.40 | 5.26 | 4.47 | 4.74 | 4.75 | 4.56 | 4.76 | 4.55 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.01 | 0.01 | 0.01 | 0.13 | 0.05 | 0.05 | 0.01 | 0.01 | 0.02 | 0.01 |
| Sulphate (% db) | 0.20 | 0.44 | 0.19 | 0.36 | 0.26 | 0.27 | 0.25 | 0.16 | 0.32 | 0.17 |
| Organic (% db) | 4.44 | 4.34 | 4.20 | 4.77 | 4.16 | 4.42 | 4.49 | 4.39 | 4.42 | 4.37 |
| HHV (MJ/kg db) | 23.33 | 24.35 | 24.54 | 23.79 | 24.96 | 24.87 | 24.61 | 24.62 | 25 | 24.32 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.29 | 4.93 | 0.64 | 5.6 | 3.63 | 3.50 | 1.54 | 0.48 | 3.9 | 0.35 |
| $Al_2O_3$ (% db) | 24.93 | 9.37 | 12.26 | 6.2 | 8.75 | 11.17 | 4.39 | 6.11 | 13.6 | 8.32 |
| $SiO_2$ (% db) | 24.80 | 4.1 | 10.02 | 6.5 | 25.40 | 26.10 | 51.3 | 30.60 | 20.6 | 32.90 |
| MgO (% db) | 11.90 | 18.34 | 19.40 | 14.01 | 13.27 | 13.63 | 10.72 | 14.99 | 12.78 | 16.14 |
| Ca0 (% db) | 8.09 | 11.04 | 12.86 | 9.44 | 8.74 | 9.14 | 7.27 | 9.99 | 8.46 | 10.75 |
| $K_2O$ (% db) | 0.24 | 0.18 | 0.18 | 0.26 | 0.62 | 0.22 | 0.17 | 0.20 | 0.23 | 0.18 |
| $Na_2O$ (% db) | 14.60 | 15.75 | 15.66 | 20.07 | 14.92 | 14.97 | 11.67 | 14.18 | 14.02 | 12.58 |
| $SO_3$ (% db) | 14.80 | 33.26 | 27.71 | 35.95 | 24.40 | 20.18 | 11.68 | 21.83 | 24.99 | 17.35 |
| $TiO_2$ (% db) | 0.00 | 0.08 | 0.15 | 0.1 | 0.28 | 0.22 | 0.24 | 0.45 | 0.22 | 0.37 |
| $SiO_2/Al_2O_3$ | 1.0 | 0.4 | 0.8 | 1.0 | 2.9 | 2.3 | 11.7 | 5.0 | 1.5 | 4.0 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.02 | 0.21 | 0.02 | 0.19 | 0.13 | 0.13 | 0.08 | 0.02 | 0.19 | 0.04 |
| Al (% db) | 0.74 | 0.27 | 0.32 | 0.25 | 0.27 | 0.31 | 0.18 | 0.21 | 0.23 | 0.28 |
| Si (% db) | 0.43 | 0.02 | 0.03 | 0.01 | 0.08 | 0.10 | 0.01 | 0.02 | 0.06 | 0.05 |
| Mg (% db) | 0.68 | 0.69 | 0.64 | 0.63 | 0.57 | 0.58 | 0.57 | 0.60 | 0.62 | 0.68 |
| Ca (% db) | 0.54 | 0.55 | 0.52 | 0.51 | 0.44 | 0.48 | 0.45 | 0.47 | 0.49 | 0.54 |
| K (% db) | 0.03 | | 0.03 | 0.02 | 0.04 | 0.03 | | 0.03 | | 0.03 |
| Na (% db) | 1.48 | 1.48 | 1.40 | 1.37 | 1.26 | 1.26 | 1.25 | 1.21 | 1.15 | 1.32 |
| Cl (% db) | 1.28 | 1.33 | 1.27 | 1.23 | 1.20 | 1.17 | 1.25 | 1.09 | 1.01 | 1.19 |
| Assay quartz (% db) | 0.20 | | 0.13 | | 1.40 | 1.21 | | 1.40 | | 0.89 |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 5.2 | 0.3 | 1.2 | 0.7 | 1.8 | 2.5 | 1.2 | 1.2 | 3.1 | 1.9 |
| Quartz (% db) | 0.2 | 0.2 | 0.2 | 0.2 | 1.2 | 1.1 | 4.9 | 1.8 | 0.4 | 2.1 |
| Quartz/kaolinite | 0.0 | 0.8 | 0.2 | 0.3 | 0.7 | 0.5 | 4.2 | 1.5 | 0.1 | 1.1 |

Appendix E2: Analytical data from coal chemistry (sheet 15 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 29 | 30 | 31 | 32 | 34 | 35 | 36 | 37 | 38 | 39 |
| Depth | 74.50 | 74.80 | 75.50 | 75.55 | 77.20 | 77.50 | 78.20 | 78.60 | 79.05 | 79.40 |
| Seam | B1 | B1 | B1 | B1 | B3 | B3 | B3 | B3 | B3 | B3 |
| Ply | B1-1 | B1-1 | B1-1 | B1-1 | B3-7 | B3-7 | B3-7 | B3-7 | B3-6 | B3-6 |
| Facies | Ib | Ib | Ib | IIa | Ib | Ib | Ib | Ia | Ib | Ib |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 50.5 | 53.35 | 44.89 | 52.06 | 51.83 | 50.39 | 51.80 | 51.9 | 53.14 | 54.52 |
| Ash (% db) | 11.85 | 13.83 | 28.17 | 17.80 | 8.41 | 7.41 | 7.55 | 7.64 | 6.89 | 7.91 |
| Volatile matter (% db) | 47.15 | 45.65 | 37.52 | 42.77 | 54.06 | 49.44 | 52.30 | 50.13 | 50.97 | 48.49 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 58.16 | | 48.34 | 51.71 | 62.23 | 61.23 | 60.68 | | | 61.72 |
| Hydrogen (% db) | 4.03 | | 3 | 3.75 | 5.01 | 4.4 | 4.78 | | | 4.23 |
| Nitrogen (% db) | | | | 0.60 | 0.50 | | 0.60 | | | 0.5 |
| Sulphur (% db) | 4.19 | 4.40 | 4.06 | 4.55 | 4.17 | 4.79 | 4.44 | 4.68 | 4.29 | 4.75 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.05 | 0.03 | 0.01 | 0.03 | 0.01 | 0.02 | 0.13 | 0.14 | 0.03 | 0.11 |
| Sulphate (% db) | 0.42 | 0.20 | 0.47 | 0.32 | 0.16 | 0.48 | 0.24 | 0.3 | 0.31 | 0.31 |
| Organic (% db) | 3.72 | 4.17 | 3.58 | 4.20 | 4.00 | 4.29 | 4.07 | 4.24 | 3.95 | 4.33 |
| HHV (MJ/kg db) | 23.55 | 22.73 | 18.28 | 20.18 | 25.76 | 24.53 | 24.95 | 24.8 | 24.93 | 23.67 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 4.02 | 1.17 | 1.35 | 1.95 | 0.51 | 7.16 | 9.51 | 5.24 | 5.05 | 5.62 |
| $Al_2O_3$ (% db) | 6.2 | 4.80 | 2.72 | 26.75 | 6.86 | 6.3 | 7.06 | 6.7 | 6.94 | 7.55 |
| $SiO_2$ (% db) | 42.8 | 63.60 | 76.1 | 48.90 | 38.70 | 5.3 | 6.60 | 3.35 | 1.30 | 4.95 |
| MgO (% db) | 9.98 | 8.25 | 2.89 | 5.95 | 14.06 | 17.48 | 17.40 | 15.57 | 20.46 | 14.19 |
| Ca0 (% db) | 6.42 | 5.40 | 1.86 | 3.90 | 9.38 | 11.05 | 11.43 | 10.06 | 13.02 | 9.33 |
| $K_2O$ (% db) | 0.13 | 0.14 | 0.07 | 0.22 | 0.21 | 0.22 | 0.22 | 0.3 | 0.20 | 0.29 |
| $Na_2O$ (% db) | 10.42 | 7.64 | 4.5 | 9.84 | 12.34 | 17 | 14.53 | 19.83 | 16.44 | 19.71 |
| $SO_3$ (% db) | 17.69 | 8.62 | 7.66 | 2.51 | 16.69 | 34.32 | 31.86 | 37.09 | 35.22 | 35.81 |
| $TiO_2$ (% db) | 0.27 | 0.21 | 0.05 | 0.12 | 0.33 | 0.07 | 0.05 | 0.1 | 0.10 | 0.1 |
| $SiO_2/Al_2O_3$ | 6.9 | 13.3 | 28.0 | 1.8 | 5.6 | 0.8 | 0.9 | 0.5 | 0.2 | 0.7 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.28 | 0.09 | 0.3 | 0.23 | 0.02 | 0.31 | 0.29 | 0.15 | 0.18 | 0.2 |
| Al (% db) | 0.24 | 0.31 | 0.31 | 2.23 | 0.27 | 0.22 | 0.23 | 0.2 | 0.24 | 0.22 |
| Si (% db) | 0.06 | 0.09 | 0.09 | 1.08 | 0.05 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 |
| Mg (% db) | 0.68 | 0.66 | 0.57 | 0.65 | 0.64 | 0.7 | 0.67 | 0.66 | 0.69 | 0.65 |
| Ca (% db) | 0.54 | 0.50 | 0.44 | 0.48 | 0.50 | 0.54 | 0.52 | 0.5 | 0.53 | 0.49 |
| K (% db) | | 0.03 | | 0.03 | 0.03 | | 0.03 | 0.02 | 0.03 | 0.02 |
| Na (% db) | 1.22 | 1.24 | 1.05 | 1.19 | 1.16 | 1.2 | 1.16 | 1.18 | 1.26 | 1.24 |
| Cl (% db) | 1.02 | 1.15 | 0.92 | 1.05 | 1.04 | 1.01 | 0.98 | 1.02 | 1.08 | 1.07 |
| Assay quartz (% db) | | 6.82 | | 2.84 | 1.27 | | 0.27 | | 0.08 | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 1.9 | 1.7 | 1.9 | 12.0 | 1.5 | 0.4 | 0.6 | 0.1 | 0.0 | 0.4 |
| Quartz (% db) | 4.2 | 8.0 | 20.5 | 3.1 | 2.6 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Quartz/kaolinite | 2.3 | 4.8 | 10.6 | 0.3 | 1.8 | 0.5 | 0.3 | 1.7 | 9.7 | 0.5 |

Appendix E2: Analytical data from coal chemistry (sheet 16 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 |
| Sample | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 |
| Depth | 80.00 | 80.50 | 81.00 | 81.45 | 81.90 | 82.40 | 82.80 | 83.50 | 84.00 | 84.40 |
| Seam | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 |
| Ply | B3-5 | B3-4 | B3-4 | B3-4 | B3-3 | B3-3 | B3-3 | B3-3 | B3-3 | B3-2 |
| Facies | Ib | Ib | Ib | Ib | Ia | Ia | Ia | Ia | Ia | IIa |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 51.37 | 50.58 | 55.13 | 53.53 | 51.09 | 55.98 | 53.67 | 56.27 | 54.61 | 52.24 |
| Ash (% db) | 6.49 | 7.05 | 7.23 | 7.57 | 8.15 | 7.38 | 7.53 | 14.03 | 8.56 | 12.27 |
| Volatile matter (% db) | 52.17 | 50.93 | 49.30 | 51.46 | 51.22 | 51.36 | 51.70 | 45.01 | 49.39 | 47.24 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | | 62.88 | | | 61.78 | 62.73 | | | | 58.75 |
| Hydrogen (% db) | | 4.41 | | | 4.43 | 4.67 | | | | 4.3 |
| Nitrogen (% db) | | | | | | 0.5 | | | | |
| Sulphur (% db) | 4.10 | 4.27 | 4.51 | 4.25 | 4.39 | 4.25 | 4.11 | 4.02 | 4.54 | 4.35 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.01 | 0.01 | 0.08 | 0.16 | 0.02 | 0.01 | 0.11 | 0.02 | 0.04 | 0.01 |
| Sulphate (% db) | 0.14 | 0.36 | 0.23 | 0.26 | 0.45 | 0.17 | 0.23 | 0.31 | 0.24 | 0.19 |
| Organic (% db) | 3.95 | 3.90 | 4.20 | 3.83 | 3.92 | 4.07 | 3.77 | 3.69 | 4.26 | 4.15 |
| HHV (MJ/kg db) | 25.44 | 25.44 | 24.98 | 25.64 | 25.18 | 24.96 | 25.29 | 23.21 | 25.09 | 23.55 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 0.52 | 4.78 | 4.59 | 7.49 | 6.47 | 0.44 | 4.42 | 2.27 | 3.58 | 0.2 |
| $Al_2O_3$ (% db) | 8.04 | 7.55 | 9.19 | 8.60 | 12.35 | 8.96 | 12.39 | 30.1 | 11.34 | 19.85 |
| $SiO_2$ (% db) | 3.80 | 2.5 | 2.40 | 5.50 | 13.9 | 5.3 | 6.40 | 31.3 | 7.40 | 27.6 |
| MgO (% db) | 23.07 | 18.95 | 18.86 | 17.91 | 13.62 | 16.2 | 15.42 | 7.07 | 18.01 | 11.14 |
| Ca0 (% db) | 14.49 | 14.26 | 13.07 | 11.61 | 9 | 10.97 | 11.45 | 4.69 | 11.95 | 5.64 |
| $K_2O$ (% db) | 0.19 | 0.23 | 0.21 | 0.22 | 0.25 | 0.29 | 0.26 | 0.24 | 0.21 | 0.24 |
| $Na_2O$ (% db) | 14.68 | 18.74 | 15.36 | 15.48 | 13.95 | 19.75 | 16.45 | 12.82 | 16.22 | 10.28 |
| $SO_3$ (% db) | 33.31 | 35.33 | 33.85 | 31.42 | 28.68 | 36.35 | 33.25 | 10.76 | 30.22 | 15.64 |
| $TiO_2$ (% db) | 0.05 | 0.1 | 0.05 | 0.65 | 0.14 | 0.18 | 0.00 | 0.14 | 0.25 | 2.02 |
| $SiO_2/Al_2O_3$ | 0.5 | 0.3 | 0.3 | 0.6 | 1.1 | 0.6 | 0.5 | 1.0 | 0.7 | 1.4 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.01 | 0.2 | 0.12 | 0.17 | 0.34 | 0.02 | 0.12 | 0.2 | 0.14 | 0.02 |
| Al (% db) | 0.24 | 0.24 | 0.32 | 0.30 | 0.28 | 0.27 | 0.39 | 0.58 | 0.43 | 0.53 |
| Si (% db) | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.05 | 0.29 | 0.04 | 0.13 |
| Mg (% db) | 0.74 | 0.69 | 0.69 | 0.67 | 0.63 | 0.68 | 0.69 | 0.58 | 0.80 | 0.78 |
| Ca (% db) | 0.52 | 0.52 | 0.53 | 0.53 | 0.49 | 0.53 | 0.55 | 0.44 | 0.68 | 0.65 |
| K (% db) | 0.03 | | 0.04 | 0.03 | | 0.02 | 0.03 | | 0.04 | |
| Na (% db) | 1.17 | 1.13 | 1.34 | 1.15 | 1.12 | 1.31 | 1.36 | 1.21 | 1.26 | 1.22 |
| Cl (% db) | 1.00 | 0.95 | 1.05 | 0.98 | 0.97 | 1.12 | 1.03 | 1.14 | 1.01 | 0.97 |
| Assay quartz (% db) | 0.12 | | 0.06 | 0.17 | | | 0.07 | | 0.34 | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 0.1 | 0.2 | 0.2 | 0.5 | 2.0 | 0.4 | 0.6 | 9.0 | 0.9 | 6.2 |
| Quartz (% db) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.5 |
| Quartz/kaolinite | 2.0 | 1.2 | 1.3 | 0.4 | 0.1 | 0.5 | 0.3 | 0.0 | 0.2 | 0.1 |

Appendix E2: Analytical data from coal chemistry (sheet 17 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B28 | B5 | B5 |
| Sample | 50 | 53 | 54 | 56 | 57 | 59 | 60 | 61 | 69.9 | 70.5 |
| Depth | 84.70 | 85.85 | 86.10 | 89.40 | 90.30 | 91.60 | 92.70 | 94.10 | 69.90 | 70.50 |
| Seam | B3 | B3 | B3 | C | C | C | C | C | B1 | B1 |
| Ply | B3-2 | B3-1 | B3-1 | C-? | C-? | C-? | C-? | C-? | B1-2 | B1-2 |
| Facies | IIa | IIa | IIa | Ib | Ib | Ib | Ib | Ib | Ia | Ib |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 49.11 | 53.34 | 49.16 | 56.74 | 55.17 | 58.37 | 54.76 | 50.99 | 55.17 | 52.84 |
| Ash (% db) | 16.77 | 10.37 | 17.20 | 16.06 | 12.46 | 8.2 | 8.20 | 18.44 | 8.66 | 11.86 |
| Volatile matter (% db) | 45.68 | 47.13 | 47.57 | 45.19 | 48.21 | 47.76 | 50.16 | 45.30 | 52.67 | 49.28 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | | | 53.60 | | 59.85 | | 61.89 | | 60.9 | 58.1 |
| Hydrogen (% db) | | | 4.20 | | 4.54 | | 4.41 | | 4.88 | 4.25 |
| Nitrogen (% db) | | | 0.50 | | 0.50 | | 0.50 | | 0.3 | |
| Sulphur (% db) | 5.81 | 4.80 | 4.05 | 4.12 | 3.91 | 4.65 | 3.97 | 4.10 | 5.29 | 5.18 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.26 | 0.02 | 0.01 | 0.11 | 0.01 | 0.06 | 0.02 | 0.11 | 0.02 | 0.01 |
| Sulphate (% db) | 1.12 | 0.33 | 0.15 | 0.34 | 0.16 | 0.44 | 0.16 | 0.46 | 0.26 | 0.37 |
| Organic (% db) | 4.43 | 4.45 | 3.89 | 3.67 | 3.74 | 4.15 | 3.79 | 3.53 | 5.01 | 4.8 |
| HHV (MJ/kg db) | 20.57 | 23.22 | 21.88 | 22.08 | 24.23 | 24.38 | 24.85 | 21.98 | 25.28 | 23.81 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 13.13 | 3.85 | 0.61 | 3.44 | 0.79 | 9.78 | 1.77 | 4.85 | 1.3 | 2.14 |
| $Al_2O_3$ (% db) | 14.31 | 19.10 | 28.04 | 5.00 | 2.90 | 2.76 | 1.58 | 0.45 | 11.2 | 10.3 |
| $SiO_2$ (% db) | 37.60 | 15.40 | 46.00 | 49.20 | 50.50 | 5 | 9.80 | 59.50 | 20.8 | 30.5 |
| MgO (% db) | 7.35 | 12.65 | 6.49 | 7.47 | 10.08 | 18.74 | 18.80 | 6.72 | 15.92 | 10.85 |
| Ca0 (% db) | 4.94 | 9.05 | 4.44 | 5.17 | 7.02 | 11.95 | 12.15 | 4.35 | 9.62 | 6.52 |
| $K_2O$ (% db) | 0.63 | 0.24 | 0.38 | 0.21 | 0.15 | 0.22 | 0.27 | 0.14 | 0.25 | 0.2 |
| $Na_2O$ (% db) | 9.22 | 13.61 | 8.86 | 11.02 | 11.05 | 15.02 | 18.96 | 7.92 | 15.05 | 14.88 |
| $SO_3$ (% db) | 9.36 | 23.90 | 1.84 | 18.65 | 16.39 | 33.79 | 34.39 | 14.48 | 25.97 | 19.88 |
| $TiO_2$ (% db) | 2.36 | 0.46 | 1.93 | 0.10 | 0.58 | 0.62 | 0.35 | 0.95 | 0.29 | 0.16 |
| $SiO_2/Al_2O_3$ | 2.6 | 0.8 | 1.6 | 9.8 | 17.4 | 1.8 | 6.2 | 132.2 | 1.9 | 3.0 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 1.28 | 0.24 | 0.05 | 0.30 | 0.06 | 0.4 | 0.08 | 0.58 | 0.03 | 0.17 |
| Al (% db) | 0.41 | 0.58 | 0.62 | 0.40 | 0.19 | 0.08 | 0.07 | 0.04 | 0.35 | 0.32 |
| Si (% db) | 0.13 | 0.09 | 0.32 | 0.04 | 0.00 | 0.01 | 0.00 | 0.00 | 0.03 | 0.01 |
| Mg (% db) | 0.69 | 0.73 | 0.64 | 0.74 | 0.72 | 0.84 | 0.89 | 0.81 | 0.73 | 0.7 |
| Ca (% db) | 0.60 | 0.66 | 0.56 | 0.63 | 0.60 | 0.64 | 0.72 | 0.64 | 0.52 | 0.51 |
| K (% db) | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | | 0.04 | 0.03 | 0.03 | |
| Na (% db) | 1.16 | 1.24 | 1.09 | 1.35 | 1.29 | 1.4 | 1.28 | 1.16 | 2 | 1.75 |
| Cl (% db) | 0.87 | 1.01 | 0.88 | 1.22 | 1.03 | 1.21 | 1.05 | 1.00 | 1.95 | 1.73 |
| Assay quartz (% db) | 2.93 | 0.23 | 2.34 | 7.28 | 5.89 | | 0.65 | 10.58 | 0.62 | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 6.1 | 3.0 | 12.2 | 2.0 | 0.9 | 0.6 | 0.3 | 0.2 | 2.5 | 3.1 |
| Quartz (% db) | 3.5 | 0.2 | 2.2 | 7.0 | 5.9 | 0.1 | 0.7 | 10.9 | 0.7 | 2.2 |
| Quartz/kaolinite | 0.6 | 0.1 | 0.2 | 3.4 | 6.4 | 0.3 | 2.0 | 51.8 | 0.3 | 0.7 |

Appendix E2: Analytical data from coal chemistry (sheet 18 of 20)

| **Sample Details** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 |
| Sample | 71 | 71.7 | 72.1 | 72.7 | 73.5 | 73.9 | 74.3 | 74.9 | 75.4 | 75.9 |
| Depth | 71.00 | 71.70 | 72.10 | 72.70 | 73.50 | 73.90 | 74.30 | 74.90 | 75.40 | 75.90 |
| Seam | B1 | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 | B3 |
| Ply | B1-1 | B3-7 | B3-7 | B3-7 | B3-6 | B3-6 | B3-6 | B3-5 | B3-5 | B3-4 |
| Facies | Ib | Ib | Ib | Ib | Ib | Ib | Ia | Ia | Ib | Ib |
| **Coal Chemistry** | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | |
| Total moisture (% ar) | 53.48 | 49.51 | 64.86 | 52.72 | 52.05 | 53.97 | 53.02 | 54.12 | 54.08 | 53.82 |
| Ash (% db) | 14.99 | 15.97 | 24.09 | 10.29 | 9.38 | 8.89 | 6.51 | 13.51 | 6.59 | 7.53 |
| Volatile matter (% db) | 45.41 | 44.43 | 37.17 | 49.45 | 48.13 | 47.81 | 48.98 | 46.99 | 50.15 | 47.69 |
| *Ultimate Analysis* | | | | | | | | | | |
| Carbon (% db) | 54.39 | 54.4 | 47.01 | 59.41 | 58.15 | 59.53 | 59.23 | 57.4 | 62.12 | 59.25 |
| Hydrogen (% db) | 3.93 | 3.84 | 3.14 | 4.33 | 4.1 | 4.25 | 4.45 | 4.21 | 4.78 | 4.45 |
| Nitrogen (% db) | 0.3 | | | 0.3 | | | | | | |
| Sulphur (% db) | 5.26 | 5.43 | 3.84 | 5.28 | 5.76 | 5.59 | 5.38 | 5.39 | 5.02 | 5.26 |
| *Forms of Sulphur* | | | | | | | | | | |
| Pyritic (% db) | 0.14 | 0.41 | 0.01 | 0.22 | 0.12 | 0.3 | 0.25 | 0.08 | 0.22 | 0.04 |
| Sulphate (% db) | 0.24 | 0.28 | 0.62 | 0.26 | 0.51 | 0.31 | 0.27 | 0.6 | 0.25 | 0.42 |
| Organic (% db) | 4.88 | 4.74 | 3.21 | 4.8 | 5.13 | 4.98 | 4.86 | 4.71 | 4.55 | 4.8 |
| HHV (MJ/kg db) | 21.72 | 21.62 | 18.98 | 24.35 | 24.05 | 24.06 | 24.2 | 23.04 | 25.09 | 24.45 |
| *Ash Composition* | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 2.01 | 4.86 | 1.95 | 4.63 | 8.12 | 7.83 | 6.7 | 6.65 | 6.44 | 4.69 |
| $Al_2O_3$ (% db) | 29.45 | 5.12 | 1.14 | 3.84 | 3.7 | 4.33 | 4.05 | 2.34 | 3.63 | 4.24 |
| $SiO_2$ (% db) | 34.5 | 57.7 | 70.4 | 40.15 | 10.4 | 30.25 | 35.85 | 41.8 | 8.05 | 1.5 |
| MgO (% db) | 8.05 | 6.29 | 2.94 | 11.79 | 14.82 | 15.57 | 14.34 | 9.86 | 20.42 | 21.7 |
| Ca0 (% db) | 4.65 | 3.83 | 1.24 | 6.98 | 8.58 | 9.18 | 8.64 | 5.92 | 11.67 | 10.92 |
| $K_2O$ (% db) | 0.26 | 0.16 | 0.13 | 0.19 | 0.25 | 0.16 | 0.28 | 0.21 | 0.19 | 0.17 |
| $Na_2O$ (% db) | 14.37 | 11 | 9.85 | 14.95 | 18.12 | 13.67 | 13.22 | 13.9 | 15.96 | 18.45 |
| $SO_3$ (% db) | 7.28 | 11.23 | 9.78 | 16.26 | 32.74 | 18.75 | 16.61 | 16.31 | 32.56 | 35.57 |
| $TiO_2$ (% db) | 0.11 | 0.1 | 0.04 | 0.22 | 0.02 | 0.15 | 0.24 | 0.02 | 0.25 | 0.1 |
| $SiO_2/Al_2O_3$ | 1.2 | 11.3 | 61.8 | 10.5 | 2.8 | 7.0 | 8.9 | 17.9 | 2.2 | 0.4 |
| *Inorganics* | | | | | | | | | | |
| Fe (% db) | 0.03 | 0.05 | 0.31 | 0.03 | 0.36 | 0.04 | 0.03 | 0.44 | 0.03 | 0.16 |
| Al (% db) | 0.96 | 0.39 | 0.14 | 0.2 | 0.15 | 0.18 | 0.16 | 0.13 | 0.13 | 0.13 |
| Si (% db) | 0.12 | 0.17 | 0.01 | 0.03 | 0.01 | 0.03 | 0.03 | 0.01 | 0.03 | 0.01 |
| Mg (% db) | 0.69 | 0.65 | 0.44 | 0.71 | 0.71 | 0.72 | 0.7 | 0.66 | 0.72 | 0.76 |
| Ca (% db) | 0.47 | 0.46 | 0.21 | 0.5 | 0.52 | 0.5 | 0.47 | 0.47 | 0.49 | 0.57 |
| K (% db) | 0.03 | 0.03 | | 0.03 | | 0.03 | 0.03 | | 0.03 | |
| Na (% db) | 1.86 | 1.61 | 2.52 | 1.76 | 1.68 | 1.89 | 1.79 | 1.75 | 1.87 | 1.94 |
| Cl (% db) | 1.63 | 1.31 | 3.22 | 1.49 | 1.43 | 1.66 | 1.61 | 1.67 | 1.67 | 1.89 |
| Assay quartz (% db) | 0.42 | 5.76 | | 2.02 | | 1.04 | 0.79 | | 0.23 | |
| **Mineral Estimates** | | | | | | | | | | |
| Kaolinite (% db) | 10.7 | 2.1 | 0.7 | 1.0 | 0.9 | 1.0 | 0.7 | 0.8 | 0.6 | 0.0 |
| Quartz (% db) | 0.2 | 8.3 | 16.6 | 3.7 | 0.6 | 2.2 | 2.0 | 5.3 | 0.2 | 0.2 |
| Quartz/kaolinite | 0.0 | 4.0 | 24.0 | 3.7 | 0.6 | 2.3 | 3.0 | 6.6 | 0.4 | 7.2 |

Appendix E2: Analytical data from coal chemistry (sheet 19 of 20)

| **Sample Details** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 |
| Sample | 76.4 | 76.9 | 77.6 | 78.1 | 78.65 | 80.95 | 81.5 | 82.5 | 83.55 | 83.95 | 84 |
| Depth | 76.40 | 76.90 | 77.60 | 78.10 | 78.65 | 80.95 | 81.50 | 82.50 | 83.55 | 83.95 | 84.00 |
| Seam | B3 | B3 | B3 | B3 | B3 | C | C | C | C | C | C |
| Ply | B3-4 | B3-3 | B3-3 | B3-3 | B1-2 | C-5 | C-5 | C-5 | C-5 | C-5 | C-5 |
| Facies | Ib | Ib | Ia | Ib | IIa | Ia | Ia | Ib | Ib | Ib | Ib |
| **Coal Chemistry** | | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | | |
| Total moisture (% ar) | 53.61 | 53.16 | 55.49 | 50.47 | 55.8 | 57.51 | 53.94 | 55.87 | 56.58 | 52.84 | 56.19 |
| Ash (% db) | 6.86 | 7.48 | 8.47 | 9.34 | 9.78 | 8.99 | 10.1 | 8.27 | 7.65 | 8.93 | 8.63 |
| Volatile matter (% db) | 49.62 | 49.19 | 48.32 | 49.58 | 48.28 | 48.96 | 49.24 | 49.07 | 48.2 | 47.71 | 48.07 |
| *Ultimate Analysis* | | | | | | | | | | | |
| Carbon (% db) | 61.95 | 60.69 | 60.42 | 61.56 | 59.98 | 60.15 | 59.37 | 62.21 | 61.13 | | 59.52 |
| Hydrogen (% db) | 4.43 | 4.31 | 4.53 | 5.44 | 4.44 | 4.25 | 4.54 | 4.51 | 4.28 | | 4.8 |
| Nitrogen (% db) | 0.3 | | | | 0.5 | | 0.3 | | | | |
| Sulphur (% db) | 5.1 | 4.75 | 4.26 | 5.48 | 4.75 | 5.3 | 4.64 | 4.63 | 4.97 | 5.34 | 4.11 |
| *Forms of Sulphur* | | | | | | | | | | | |
| Pyritic (% db) | 0.12 | 0.02 | 0.05 | 0.02 | 0.12 | 0.02 | 0.04 | 0.16 | 0.34 | | 0.02 |
| Sulphate (% db) | 0.26 | 0.37 | 0.27 | 0.43 | 0.26 | 0.31 | 0.18 | 0.26 | 0.3 | | 0.26 |
| Organic (% db) | 4.72 | 4.36 | 3.94 | 5.03 | 4.37 | 4.97 | 4.42 | 4.21 | 4.33 | | 3.83 |
| HHV (MJ/kg db) | 25.29 | 25.12 | 24.59 | 24.23 | 24.33 | 24.31 | 24.38 | 24.83 | 24.88 | 24.46 | 24.71 |
| *Ash Composition* | | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 3.47 | 3.95 | 1.58 | 4.55 | 0.7 | 3.28 | 1.35 | 3.95 | 7.12 | 12.84 | 1.41 |
| $Al_2O_3$ (% db) | 4.89 | 6.9 | 7.28 | 11.06 | 6.43 | 7.82 | 8.89 | 7.26 | 1.51 | 4.09 | 0.2 |
| $SiO_2$ (% db) | 8.6 | 1.8 | 30.4 | 10.5 | 49.8 | 3.2 | 27.7 | 2.7 | 3.25 | 0.9 | 29.1 |
| MgO (% db) | 17.1 | 21.2 | 10.87 | 16.74 | 14.26 | 17.35 | 11.96 | 18.53 | 19.69 | 17.68 | 15.72 |
| Ca0 (% db) | 10.1 | 11.1 | 6.95 | 10.88 | 9.18 | 10.85 | 7.94 | 11.51 | 11.16 | 9.95 | 9.41 |
| $K_2O$ (% db) | 0.22 | 0.16 | 0.19 | 0.17 | 0.12 | 0.24 | 0.16 | 0.25 | 0.25 | 0.19 | 0.25 |
| $Na_2O$ (% db) | 20.45 | 18.54 | 15.47 | 16.62 | 9.89 | 18.46 | 18.26 | 17.46 | 17.56 | 18.3 | 17.15 |
| $SO_3$ (% db) | 33.97 | 32.98 | 21.1 | 26.85 | 8 | 35.69 | 24.94 | 35.46 | 37.2 | 34.2 | 22.01 |
| $TiO_2$ (% db) | 0.26 | 0.14 | 0.5 | 0.3 | 2.06 | 0.05 | 0.38 | 0.34 | 0.33 | 0.1 | 0.02 |
| $SiO_2/Al_2O_3$ | 1.8 | 0.3 | 4.2 | 0.9 | 7.7 | 0.4 | 3.1 | 0.4 | 2.2 | 0.2 | 145.5 |
| *Inorganics* | | | | | | | | | | | |
| Fe (% db) | 0.03 | 0.15 | 0.03 | 0.23 | 0.03 | 0.15 | 0.03 | 0.03 | 0.03 | 0.3 | 0.07 |
| Al (% db) | 0.2 | 0.2 | 0.34 | 0.32 | 0.42 | 0.34 | 0.38 | 0.31 | 0.05 | 0.19 | 0.01 |
| Si (% db) | 0.03 | 0.01 | 0.03 | 0.04 | 0.07 | 0.01 | 0.07 | 0.03 | 0.03 | 0.01 | 0.01 |
| Mg (% db) | 0.74 | 0.74 | 0.62 | 0.77 | 0.8 | 0.83 | 0.76 | 0.82 | 0.87 | 0.87 | 0.78 |
| Ca (% db) | 0.53 | 0.59 | 0.46 | 0.62 | 0.62 | 0.65 | 0.58 | 0.61 | 0.6 | 0.65 | 0.56 |
| K (% db) | 0.03 | | 0.03 | | 0.03 | | 0.03 | 0.03 | 0.03 | | |
| Na (% db) | 1.84 | 1.85 | 1.8 | 1.74 | 1.94 | 1.84 | 1.9 | 1.97 | 2.03 | 1.91 | 1.87 |
| Cl (% db) | 1.6 | 1.76 | 1.71 | 1.53 | 1.74 | 1.79 | 1.67 | 1.79 | 1.81 | 1.87 | 1.83 |
| Assay quartz (% db) | 0.01 | | 1.89 | | 0.84 | | 1.61 | 0.11 | 0.17 | | |
| **Mineral Estimates** | | | | | | | | | | | |
| Kaolinite (% db) | 0.8 | 0.1 | 1.6 | 1.7 | 1.6 | 0.2 | 2.3 | 0.1 | 0.3 | 0.0 | 0.0 |
| Quartz (% db) | 0.2 | 0.2 | 1.8 | 0.2 | 4.1 | 0.2 | 1.7 | 0.2 | 0.1 | 0.2 | 2.5 |
| Quartz/kaolinite | 0.2 | 2.7 | 1.2 | 0.1 | 2.6 | 1.1 | 0.8 | 4.0 | 0.4 | 251.4 | 57.1 |

Appendix E2: Analytical data from coal chemistry (sheet 20 of 20)

| **Sample Details** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hole | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 | B5 |
| Sample | 84.5 | 84.95 | 85.5 | 85.95 | 86.5 | 86.95 | 88 | 88.5 | 89 | 90 | 91 |
| Depth | 84.50 | 84.95 | 85.50 | 85.95 | 86.50 | 86.95 | 88.00 | 88.50 | 89.00 | 90.00 | 91.00 |
| Seam | C | C | C | C | C | C | C | C | C | C | C |
| Ply | C-5 | C-5 | C-4 | C-4 | C-3 | C-3 | C-3 | C-3 | C-3 | C-2 | C-1 |
| Facies | Ib | Ib | Ia | Ia | Ib | Ib | Ib | Ib | Ib | Ia | IIa |
| **Coal Chemistry** | | | | | | | | | | | |
| *Proximate Analysis* | | | | | | | | | | | |
| Total moisture (% ar) | 56.88 | 57.09 | 76.37 | 59.79 | 56.66 | 57.17 | 56.8 | 50.2 | 55.83 | 56.79 | 56.51 |
| Ash (% db) | 7.37 | 9.52 | 7.5 | 9.29 | 7.5 | 6.7 | 7.31 | 8.55 | 8.81 | 11.81 | 13.38 |
| Volatile matter (% db) | 48 | 48.22 | 38.44 | 43.85 | 49.04 | 49.69 | 49.57 | 51.15 | 50.29 | 48.55 | 44.21 |
| *Ultimate Analysis* | | | | | | | | | | | |
| Carbon (% db) | 61.1 | 60.12 | 55.23 | 59.84 | 61.16 | 62.87 | 62.69 | 61.17 | 61.05 | 59.96 | 57.84 |
| Hydrogen (% db) | 4.75 | 4.26 | 3.9 | 4.38 | 4.38 | 4.87 | 4.75 | 4.73 | 4.89 | 4.73 | 4.11 |
| Nitrogen (% db) | | | 0.2 | | | 0.5 | | | 0.6 | | 0.5 |
| Sulphur (% db) | 4.21 | 4.24 | 4.74 | 4.51 | 4.19 | 3.92 | 3.88 | 3.8 | 3.83 | 3.73 | 4.44 |
| *Forms of Sulphur* | | | | | | | | | | | |
| Pyritic (% db) | 0.09 | 0.01 | 0.47 | 0.2 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.4 |
| Sulphate (% db) | 0.24 | 0.26 | 0.73 | 0.27 | 0.22 | 0.21 | 0.21 | 0.24 | 0.22 | 0.21 | 0.35 |
| Organic (% db) | 3.88 | 3.97 | 3.54 | 4.04 | 3.96 | 3.7 | 3.66 | 3.55 | 3.6 | 3.51 | 3.69 |
| HHV (MJ/kg db) | 24.83 | 24.55 | 22.36 | 24.43 | 25.47 | 26.1 | 25.83 | 25.95 | 25.78 | 24.61 | 23.38 |
| *Ash Composition* | | | | | | | | | | | |
| $Fe_2O_3$ (% db) | 2.65 | 1.55 | 12.24 | 4.06 | 0.61 | 0.47 | 0.63 | 0.68 | 0.51 | 3.36 | 6.4 |
| $Al_2O_3$ (% db) | 0.46 | 0.1 | 0.74 | 0.54 | 0.26 | 0.46 | 0.97 | 0.55 | 2.4 | 11.35 | 9 |
| $SiO_2$ (% db) | 35.45 | 28.5 | 11.3 | 39.05 | 13.2 | 16.75 | 25.25 | 27.1 | 31.6 | 21.55 | 16.75 |
| MgO (% db) | 19.13 | 17.38 | 13.98 | 13.12 | 21.15 | 19.12 | 21.92 | 20.52 | 16.87 | 17.73 | 12.76 |
| Ca0 (% db) | 11.12 | 10.15 | 4.86 | 7.38 | 11.34 | 10.83 | 12.67 | 11.58 | 10.36 | 11.67 | 8.38 |
| $K_2O$ (% db) | 0.23 | 0.16 | 0.3 | 0.13 | 0.24 | 0.23 | 0.17 | 0.13 | 0.13 | 0.16 | 0.24 |
| $Na_2O$ (% db) | 12.01 | 15.95 | 23.02 | 13.93 | 18.22 | 18.56 | 12.94 | 15.5 | 15.07 | 13.14 | 16.4 |
| $SO_3$ (% db) | 16.76 | 22.12 | 19.8 | 19.24 | 30.71 | 27.3 | 21.85 | 21.74 | 20.61 | 18.21 | 26.54 |
| $TiO_2$ (% db) | 0.46 | 0.02 | 0.32 | 0.55 | 0.1 | 0.56 | 0.55 | 0.26 | 1.5 | 0.49 | 0.68 |
| $SiO_2/Al_2O_3$ | 77.1 | 285.0 | 15.3 | 72.3 | 50.8 | 36.4 | 26.0 | 49.3 | 13.2 | 1.9 | 1.9 |
| *Inorganics* | | | | | | | | | | | |
| Fe (% db) | 0.03 | 0.07 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.17 |
| Al (% db) | 0.03 | 0.01 | 0.04 | 0.03 | 0.01 | 0.03 | 0.03 | 0.02 | 0.11 | 0.35 | 0.58 |
| Si (% db) | 0.03 | 0.01 | 0.03 | 0.03 | 0.01 | 0.03 | 0.03 | 0.01 | 0.03 | 0.03 | 0.09 |
| Mg (% db) | 0.78 | 0.87 | 0.67 | 0.75 | 0.86 | 0.8 | 0.81 | 0.8 | 0.79 | 0.79 | 1 |
| Ca (% db) | 0.52 | 0.63 | 0.32 | 0.5 | 0.62 | 0.55 | 0.55 | 0.59 | 0.55 | 0.58 | 0.76 |
| K (% db) | 0.03 | | 0.05 | 0.03 | | 0.03 | 0.03 | | 0.03 | 0.03 | 0.03 |
| Na (% db) | 1.96 | 1.91 | 3.87 | 2.07 | 1.89 | 1.95 | 1.91 | 1.91 | 1.95 | 1.94 | 2.01 |
| Cl (% db) | 1.85 | 1.86 | 5.07 | 2.01 | 1.91 | 1.83 | 1.81 | 1.87 | 1.83 | 1.85 | 1.66 |
| Assay quartz (% db) | 1.41 | | 0.47 | 2.89 | | 0.94 | 1.17 | | 2.15 | 3.79 | 1.25 |
| **Mineral Estimates** | | | | | | | | | | | |
| Kaolinite (% db) | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 | 0.2 | 0.1 | 0.5 | 3.4 | 3.0 |
| Quartz (% db) | 2.6 | 2.7 | 0.8 | 3.6 | 1.0 | 1.1 | 1.8 | 2.3 | 2.5 | 1.0 | 0.8 |
| Quartz/kaolinite | 30.0 | 112.2 | 5.6 | 28.1 | 19.6 | 13.9 | 9.8 | 19.0 | 4.7 | 0.3 | 0.3 |

Key to Appendix E2:

% db = weight percent, dry-coal basis, % ad = weight percent, air dried basis
Blank field indicates testing was not undertaken
Coal chemistry determined in line with relevant Australian Standards (see Section 3.6.1)
Mineral estimates determined in line with methodology elaborated in Appendix E1

Appendix E3: Quartz and kaolinite mineral estimates (Sheet 1 of 7)

| Deposit | Borehole ID | Easting | Northing | Seam | $SiO_2$ (% db) | $Al_2O_3$ (% db) | Estimated Quartz (% db) | Estimated Kaolinite (% db) |
|---|---|---|---|---|---|---|---|---|
| Lochiel | V443 | 241500.00 | 6250500.00 | F | 31.7 | 24.2 | 1.0 | 10.0 |
| Lochiel | V456 | 239359.00 | 6248498.00 | F | 33.2 | 16.4 | 2.5 | 7.4 |
| Lochiel | V462 | 240500.00 | 6247500.00 | F | 35.3 | 20.6 | 2.1 | 9.7 |
| Lochiel | V492 | 240438.00 | 6245499.00 | F | 46.7 | 19.0 | 6.4 | 8.8 |
| Lochiel | V499 | 239586.00 | 6250651.00 | F | 42.4 | 21.4 | 5.4 | 10.6 |
| Lochiel | V510 | 240631.00 | 6248210.00 | F | 21.6 | 20.7 | 0.2 | 6.0 |
| Lochiel | V560 | 238330.00 | 6245527.00 | F | 27.1 | 23.5 | 0.4 | 7.2 |
| Lochiel | V562 | 241000.00 | 6246500.00 | F | 37.7 | 20.6 | 3.3 | 7.2 |
| Lochiel | V565 | 240243.00 | 6248013.00 | F | 34.9 | 22.5 | 1.6 | 10.4 |
| Lochiel | V572 | 239480.00 | 6249573.00 | F | 29.1 | 21.9 | 0.5 | 8.8 |
| Lochiel | V604 | 240454.00 | 6246804.00 | F | 40.5 | 20.4 | 3.2 | 7.3 |
| Lochiel | V632 | 240738.00 | 6250145.00 | F | 27.2 | 23.1 | 0.4 | 9.2 |
| Lochiel | V634 | 240480.00 | 6245930.00 | F | 37.6 | 19.4 | 3.9 | 7.0 |
| Lochiel | V664 | 239466.92 | 6245598.66 | F | 35.5 | 21.5 | 2.1 | 9.4 |
| Lochiel | V679 | 241749.88 | 6246500.26 | F | 31.1 | 24.2 | 0.4 | 9.0 |
| Lochiel | V680 | 239500.82 | 6245000.58 | F | 61.3 | 19.0 | 9.6 | 11.8 |
| Lochiel | V681 | 238991.62 | 6244988.63 | F | 41.1 | 29.5 | 1.3 | 15.0 |
| Lochiel | V682 | 239979.26 | 6245996.54 | F | 51.8 | 19.0 | 5.5 | 9.1 |
| Lochiel | V684 | 240213.65 | 6245504.87 | F | 40.1 | 27.4 | 2.1 | 11.2 |
| Lochiel | V685 | 239993.95 | 6244983.98 | F | 43.8 | 21.4 | 3.9 | 10.4 |
| Lochiel | V686 | 239500.34 | 6246000.13 | F | 28.1 | 29.4 | 0.3 | 8.5 |
| Lochiel | V690 | 241500.58 | 6245996.79 | F | 60.5 | 14.3 | 11.0 | 9.1 |
| Lochiel | V691 | 242001.24 | 6245991.97 | F | 36.3 | 15.3 | 3.7 | 7.9 |
| Lochiel | V694 | 242004.40 | 6245502.38 | F | 51.3 | 18.5 | 5.8 | 9.2 |
| Lochiel | V695 | 242502.08 | 6245998.34 | F | 52.4 | 22.4 | 6.7 | 14.4 |
| Lochiel | V696 | 240999.14 | 6244991.27 | F | 42.2 | 19.9 | 5.2 | 8.0 |
| Lochiel | V698 | 241499.78 | 6246999.88 | F | 26.0 | 23.3 | 0.8 | 6.4 |
| Lochiel | V699 | 241249.79 | 6247498.18 | F | 31.5 | 18.7 | 1.8 | 8.5 |
| Lochiel | V700 | 241748.44 | 6247998.89 | F | 29.2 | 18.8 | 1.1 | 7.5 |
| Lochiel | V704 | 241001.40 | 6245498.96 | F | 36.6 | 23.0 | 3.0 | 7.7 |
| Lochiel | V705 | 240999.32 | 6246039.55 | F | 27.1 | 22.7 | 1.5 | 4.8 |
| Lochiel | V706 | 241748.95 | 6247501.31 | F | 43.3 | 20.9 | 3.6 | 10.1 |
| Lochiel | V707 | 241248.65 | 6248001.39 | F | 27.2 | 26.2 | 0.7 | 6.4 |
| Lochiel | V708 | 241251.50 | 6248503.19 | F | 27.9 | 20.8 | 0.8 | 8.0 |
| Lochiel | V711 | 242876.42 | 6246499.13 | F | 66.3 | 8.3 | 14.1 | 5.2 |
| Lochiel | V712 | 240793.57 | 6247905.34 | F | 34.8 | 23.9 | 1.4 | 12.6 |
| Lochiel | V713 | 240748.86 | 6247501.81 | F | 31.8 | 20.7 | 1.8 | 7.3 |
| Lochiel | V714 | 240211.76 | 6247497.37 | F | 28.3 | 24.1 | 1.1 | 7.3 |
| Lochiel | V715 | 239845.89 | 6248013.96 | F | 24.9 | 16.1 | 2.0 | 4.9 |
| Lochiel | V722 | 240000.74 | 6246497.73 | F | 64.8 | 7.8 | 12.2 | 4.3 |
| Lochiel | V726 | 240492.42 | 6244981.27 | F | 35.2 | 23.8 | 1.1 | 9.2 |
| Lochiel | V727 | 240100.50 | 6247130.39 | F | 26.8 | 17.5 | 1.7 | 5.3 |
| Lochiel | V731 | 238939.99 | 6248500.01 | F | 43.6 | 22.1 | 3.7 | 11.3 |
| Lochiel | V733 | 240999.60 | 6247000.17 | F | 42.4 | 16.8 | 4.3 | 7.0 |
| Lochiel | V734 | 241627.54 | 6249059.94 | F | 38.2 | 15.5 | 3.8 | 7.5 |
| Lochiel | V751 | 239151.66 | 6247546.84 | F | 17.0 | 19.6 | 0.3 | 3.2 |
| Lochiel | V753 | 239364.03 | 6247997.51 | F | 37.6 | 21.5 | 4.1 | 7.8 |
| Lochiel | V754 | 238987.31 | 6246985.82 | F | 54.1 | 20.1 | 6.7 | 11.2 |
| Lochiel | V757 | 241838.01 | 6246874.96 | F | 37.9 | 19.4 | 2.3 | 7.5 |
| Lochiel | V356 | 242343.00 | 6250517.00 | G | 27.7 | 20.8 | 1.6 | 6.8 |
| Lochiel | V437 | 240410.00 | 6246472.00 | G | 17.3 | 16.4 | 0.4 | 3.3 |
| Lochiel | V443 | 241500.00 | 6250500.00 | G | 24.0 | 19.2 | 1.0 | 4.3 |

Appendix E3: Quartz and kaolinite mineral estimates (Sheet 2 of 7)

| Deposit | Borehole ID | Easting | Northing | Seam | $SiO_2$ (% db) | $Al_2O_3$ (% db) | Estimated Quartz (% db) | Estimated Kaolinite (% db) |
|---|---|---|---|---|---|---|---|---|
| Lochiel | V456 | 239359.00 | 6248498.00 | G | 31.1 | 13.9 | 3.4 | 4.6 |
| Lochiel | V457 | 238430.00 | 6246500.00 | G | 14.5 | 9.2 | 0.4 | 2.2 |
| Lochiel | V459 | 240500.00 | 6242460.00 | G | 34.2 | 3.0 | 4.4 | 0.8 |
| Lochiel | V461 | 241500.00 | 6244500.00 | G | 43.4 | 8.5 | 5.9 | 3.3 |
| Lochiel | V462 | 240500.00 | 6247500.00 | G | 29.3 | 16.3 | 1.4 | 5.6 |
| Lochiel | V465 | 242500.00 | 6249500.00 | G | 30.7 | 15.9 | 2.3 | 6.7 |
| Lochiel | V468 | 241500.00 | 6251500.00 | G | 31.7 | 17.0 | 2.7 | 7.0 |
| Lochiel | V471 | 240439.00 | 6240426.00 | G | 46.3 | 2.3 | 8.1 | 0.9 |
| Lochiel | V486 | 239516.00 | 6242510.00 | G | 30.0 | 6.4 | 5.3 | 1.3 |
| Lochiel | V489 | 240461.00 | 6241377.00 | G | 23.5 | 2.9 | 2.4 | 0.8 |
| Lochiel | V490 | 240505.00 | 6244518.00 | G | 23.1 | 17.4 | 1.2 | 4.7 |
| Lochiel | V492 | 240438.00 | 6245499.00 | G | 26.0 | 15.3 | 2.2 | 3.9 |
| Lochiel | V499 | 239586.00 | 6250651.00 | G | 26.7 | 16.6 | 2.0 | 4.3 |
| Lochiel | V508 | 242459.00 | 6245585.00 | G | 18.9 | 14.2 | 0.9 | 3.7 |
| Lochiel | V510 | 240631.00 | 6248210.00 | G | 15.0 | 15.3 | 0.3 | 2.9 |
| Lochiel | V511 | 242503.00 | 6247505.00 | G | 25.3 | 17.7 | 1.3 | 5.3 |
| Lochiel | V531 | 243081.00 | 6244850.00 | G | 24.3 | 4.2 | 3.2 | 1.2 |
| Lochiel | V533 | 241979.00 | 6243393.00 | G | 17.5 | 9.7 | 4.5 | 3.1 |
| Lochiel | V537 | 241480.00 | 6241968.00 | G | 22.7 | 4.1 | 2.0 | 1.2 |
| Lochiel | V546 | 240488.00 | 6241334.00 | G | 21.9 | 3.5 | 2.8 | 0.9 |
| Lochiel | V560 | 238330.00 | 6245527.00 | G | 13.9 | 19.5 | 0.3 | 2.6 |
| Lochiel | V562 | 241000.00 | 6246500.00 | G | 19.3 | 19.2 | 0.5 | 4.1 |
| Lochiel | V563 | 241974.00 | 6249454.00 | G | 23.7 | 16.3 | 1.4 | 4.5 |
| Lochiel | V565 | 240243.00 | 6248013.00 | G | 19.5 | 18.1 | 0.4 | 4.4 |
| Lochiel | V571 | 240491.00 | 6250999.00 | G | 27.4 | 17.3 | 0.8 | 5.5 |
| Lochiel | V572 | 239480.00 | 6249573.00 | G | 25.0 | 16.0 | 1.9 | 3.7 |
| Lochiel | V582 | 238867.00 | 6246491.00 | G | 24.6 | 13.3 | 2.0 | 2.4 |
| Lochiel | V598 | 242222.00 | 6244182.00 | G | 12.0 | 10.0 | 1.0 | 1.7 |
| Lochiel | V599 | 242529.00 | 6242890.00 | G | 41.3 | 12.2 | 4.5 | 5.0 |
| Lochiel | V604 | 240454.00 | 6246804.00 | G | 12.0 | 16.0 | 0.3 | 1.9 |
| Lochiel | V632 | 240738.00 | 6250145.00 | G | 41.5 | 17.1 | 3.8 | 7.1 |
| Lochiel | V634 | 240480.00 | 6245930.00 | G | 23.7 | 16.5 | 1.2 | 3.9 |
| Lochiel | V661 | 240998.72 | 6241000.04 | G | 42.4 | 4.7 | 4.9 | 1.5 |
| Lochiel | V662 | 240861.75 | 6240500.83 | G | 56.4 | 4.2 | 8.8 | 1.8 |
| Lochiel | V663 | 239999.66 | 6241001.52 | G | 25.8 | 3.8 | 2.1 | 1.0 |
| Lochiel | V664 | 239466.92 | 6245598.66 | G | 21.3 | 16.3 | 0.7 | 4.0 |
| Lochiel | V665 | 240500.76 | 6240999.17 | G | 19.1 | 3.3 | 2.1 | 1.0 |
| Lochiel | V666 | 240149.74 | 6241502.06 | G | 27.2 | 3.1 | 2.8 | 0.7 |
| Lochiel | V667 | 239701.21 | 6241499.79 | G | 16.9 | 2.5 | 2.3 | 0.6 |
| Lochiel | V669 | 239324.37 | 6241998.54 | G | 29.4 | 4.2 | 3.5 | 1.1 |
| Lochiel | V670 | 241250.81 | 6241498.26 | G | 29.7 | 4.5 | 4.7 | 1.2 |
| Lochiel | V671 | 240011.97 | 6242004.96 | G | 47.0 | 3.3 | 7.6 | 1.2 |
| Lochiel | V672 | 241000.04 | 6242500.18 | G | 13.7 | 5.5 | 1.1 | 0.8 |
| Lochiel | V673 | 242910.81 | 6242740.32 | G | 51.6 | 4.2 | 7.8 | 1.8 |
| Lochiel | V674 | 242410.85 | 6242499.54 | G | 45.1 | 6.7 | 5.3 | 2.4 |
| Lochiel | V675 | 243001.39 | 6243499.28 | G | 43.4 | 4.3 | 6.8 | 1.3 |
| Lochiel | V676 | 241999.67 | 6243002.04 | G | 16.9 | 14.0 | 0.7 | 3.0 |
| Lochiel | V677 | 241498.62 | 6242999.89 | G | 20.4 | 12.3 | 1.6 | 2.4 |
| Lochiel | V678 | 242248.93 | 6246499.22 | G | 23.3 | 17.9 | 0.9 | 4.8 |
| Lochiel | V679 | 241749.88 | 6246500.26 | G | 26.1 | 17.7 | 1.2 | 5.0 |
| Lochiel | V680 | 239500.82 | 6245000.58 | G | 20.1 | 19.4 | 0.5 | 4.1 |
| Lochiel | V681 | 238991.62 | 6244988.63 | G | 21.8 | 21.3 | 0.4 | 4.7 |

Appendix E3: Quartz and kaolinite mineral estimates (Sheet 3 of 7)

| Deposit | Borehole ID | Easting | Northing | Seam | $SiO_2$ (% db) | $Al_2O_3$ (% db) | Estimated Quartz (% db) | Estimated Kaolinite (% db) |
|---|---|---|---|---|---|---|---|---|
| Lochiel | V682 | 239979.26 | 6245996.54 | G | 25.5 | 19.5 | 1.2 | 4.9 |
| Lochiel | V683 | 239000.07 | 6245999.96 | G | 31.7 | 16.6 | 2.1 | 4.5 |
| Lochiel | V684 | 240213.65 | 6245504.87 | G | 24.6 | 14.8 | 1.3 | 4.4 |
| Lochiel | V685 | 239993.95 | 6244983.98 | G | 21.7 | 17.2 | 1.0 | 4.0 |
| Lochiel | V686 | 239500.34 | 6246000.13 | G | 30.7 | 16.8 | 2.6 | 4.5 |
| Lochiel | V687 | 239358.19 | 6244482.24 | G | 27.9 | 15.3 | 2.1 | 4.1 |
| Lochiel | V688 | 239500.00 | 6244000.17 | G | 18.2 | 16.0 | 0.4 | 3.6 |
| Lochiel | V689 | 238500.00 | 6244500.00 | G | 25.8 | 15.6 | 0.9 | 4.5 |
| Lochiel | V690 | 241500.58 | 6245996.79 | G | 21.0 | 16.9 | 0.6 | 4.3 |
| Lochiel | V691 | 242001.24 | 6245991.97 | G | 24.6 | 17.1 | 1.4 | 4.5 |
| Lochiel | V692 | 243375.72 | 6242998.77 | G | 66.3 | 3.5 | 15.7 | 1.9 |
| Lochiel | V693 | 240748.40 | 6242001.06 | G | 34.4 | 4.8 | 5.5 | 1.2 |
| Lochiel | V694 | 242004.40 | 6245502.38 | G | 19.9 | 19.6 | 0.7 | 3.9 |
| Lochiel | V695 | 242502.08 | 6245998.34 | G | 20.9 | 13.5 | 2.4 | 3.1 |
| Lochiel | V696 | 240999.14 | 6244991.27 | G | 23.2 | 18.0 | 1.0 | 4.7 |
| Lochiel | V697 | 241501.60 | 6244996.92 | G | 19.9 | 15.6 | 0.6 | 4.2 |
| Lochiel | V698 | 241499.78 | 6246999.88 | G | 26.2 | 13.8 | 2.2 | 3.6 |
| Lochiel | V699 | 241249.79 | 6247498.18 | G | 26.4 | 14.6 | 2.1 | 3.6 |
| Lochiel | V700 | 241748.44 | 6247998.89 | G | 16.9 | 16.0 | 0.5 | 3.1 |
| Lochiel | V701 | 241749.83 | 6248503.42 | G | 19.5 | 17.1 | 0.6 | 4.4 |
| Lochiel | V702 | 239999.01 | 6242499.62 | G | 22.4 | 7.5 | 2.6 | 1.2 |
| Lochiel | V703 | 241004.74 | 6244527.62 | G | 18.7 | 15.6 | 0.8 | 2.9 |
| Lochiel | V704 | 241001.40 | 6245498.96 | G | 16.2 | 18.0 | 0.4 | 3.2 |
| Lochiel | V705 | 240999.32 | 6246039.55 | G | 17.8 | 17.3 | 0.4 | 3.3 |
| Lochiel | V706 | 241748.95 | 6247501.31 | G | 35.4 | 14.7 | 3.0 | 5.1 |
| Lochiel | V707 | 241248.65 | 6248001.39 | G | 16.4 | 15.1 | 0.5 | 2.7 |
| Lochiel | V708 | 241251.50 | 6248503.19 | G | 30.3 | 16.5 | 2.2 | 4.6 |
| Lochiel | V709 | 242885.00 | 6244725.00 | G | 22.7 | 6.2 | 2.2 | 2.0 |
| Lochiel | V711 | 242876.42 | 6246499.13 | G | 20.1 | 16.1 | 0.5 | 4.3 |
| Lochiel | V712 | 240793.57 | 6247905.34 | G | 33.7 | 20.9 | 2.2 | 7.4 |
| Lochiel | V713 | 240748.86 | 6247501.81 | G | 22.5 | 20.1 | 0.5 | 5.5 |
| Lochiel | V714 | 240211.76 | 6247497.37 | G | 21.3 | 18.5 | 0.6 | 4.2 |
| Lochiel | V715 | 239845.89 | 6248013.96 | G | 20.9 | 12.6 | 1.5 | 2.7 |
| Lochiel | V716 | 241500.00 | 6242450.00 | G | 21.1 | 4.5 | 3.4 | 1.2 |
| Lochiel | V717 | 239579.93 | 6243000.02 | G | 29.4 | 5.4 | 5.4 | 1.7 |
| Lochiel | V720 | 239603.73 | 6243613.21 | G | 37.6 | 2.9 | 4.6 | 1.1 |
| Lochiel | V721 | 239500.46 | 6247500.46 | G | 48.5 | 11.3 | 10.5 | 4.3 |
| Lochiel | V722 | 240000.74 | 6246497.73 | G | 24.8 | 15.6 | 1.5 | 3.6 |
| Lochiel | V723 | 240999.36 | 6242998.89 | G | 21.5 | 11.3 | 2.6 | 3.4 |
| Lochiel | V724 | 239948.00 | 6243446.00 | G | 27.4 | 4.8 | 4.9 | 1.4 |
| Lochiel | V725 | 240095.62 | 6243978.67 | G | 27.6 | 9.2 | 3.9 | 1.8 |
| Lochiel | V726 | 240492.42 | 6244981.27 | G | 19.7 | 17.9 | 0.5 | 4.3 |
| Lochiel | V727 | 240100.50 | 6247130.39 | G | 26.2 | 11.5 | 2.4 | 2.7 |
| Lochiel | V728 | 242700.77 | 6243798.72 | G | 21.3 | 6.5 | 2.2 | 2.5 |
| Lochiel | V729 | 242500.00 | 6243500.00 | G | 34.9 | 8.2 | 4.0 | 3.0 |
| Lochiel | V730 | 243250.09 | 6243999.84 | G | 34.5 | 14.0 | 3.6 | 7.0 |
| Lochiel | V731 | 238939.99 | 6248500.01 | G | 33.7 | 14.8 | 3.4 | 4.9 |
| Lochiel | V733 | 240999.60 | 6247000.17 | G | 23.9 | 14.0 | 1.7 | 3.3 |
| Lochiel | V734 | 241627.54 | 6249059.94 | G | 25.2 | 13.6 | 1.5 | 4.3 |
| Lochiel | V736 | 240999.99 | 6243500.00 | G | 16.8 | 9.3 | 1.4 | 2.4 |
| Lochiel | V737 | 242000.80 | 6245000.23 | G | 16.7 | 13.9 | 0.4 | 3.3 |
| Lochiel | V738 | 242501.21 | 6245000.14 | G | 23.2 | 11.8 | 1.8 | 3.8 |

Appendix E3: Quartz and kaolinite mineral estimates (Sheet 4 of 7)

| Deposit | Borehole ID | Easting | Northing | Seam | $SiO_2$ (% db) | $Al_2O_3$ (% db) | Estimated Quartz (% db) | Estimated Kaolinite (% db) |
|---|---|---|---|---|---|---|---|---|
| Lochiel | V739 | 242874.38 | 6245160.40 | G | 30.0 | 6.1 | 3.9 | 1.5 |
| Lochiel | V740 | 239999.94 | 6243000.00 | G | 22.6 | 9.4 | 3.7 | 3.1 |
| Lochiel | V741 | 241999.86 | 6244499.92 | G | 25.1 | 8.3 | 2.2 | 2.2 |
| Lochiel | V742 | 241500.04 | 6243999.66 | G | 13.8 | 8.4 | 0.6 | 2.7 |
| Lochiel | V743 | 241000.04 | 6243999.66 | G | 14.4 | 9.3 | 0.6 | 2.0 |
| Lochiel | V744 | 241456.12 | 6243507.98 | G | 28.1 | 12.2 | 3.7 | 3.8 |
| Lochiel | V745 | 240499.91 | 6242999.83 | G | 29.3 | 12.7 | 3.1 | 3.8 |
| Lochiel | V746 | 241956.33 | 6242040.81 | G | 49.0 | 3.4 | 7.0 | 1.3 |
| Lochiel | V747 | 241750.00 | 6241499.78 | G | 66.4 | 1.6 | 14.8 | 0.8 |
| Lochiel | V748 | 241998.32 | 6244000.35 | G | 25.4 | 7.8 | 2.2 | 2.0 |
| Lochiel | V749 | 240691.05 | 6244023.11 | G | 20.2 | 8.8 | 2.2 | 1.8 |
| Lochiel | V751 | 239151.66 | 6247546.84 | G | 17.0 | 13.4 | 0.7 | 2.3 |
| Lochiel | V753 | 239364.03 | 6247997.51 | G | 38.5 | 12.1 | 4.9 | 4.0 |
| Lochiel | V754 | 238987.31 | 6246985.82 | G | 22.2 | 17.0 | 1.2 | 3.3 |
| Lochiel | V755 | 242855.21 | 6242219.26 | G | 23.0 | 7.4 | 2.0 | 2.7 |
| Lochiel | V756 | 243192.02 | 6245741.79 | G | 40.0 | 12.2 | 5.4 | 5.1 |
| Lochiel | V757 | 241838.01 | 6246874.96 | G | 28.7 | 16.6 | 1.6 | 5.4 |
| Lochiel | V356 | 242343.00 | 6250517.00 | H | 60.3 | 9.2 | 12.2 | 5.0 |
| Lochiel | V443 | 241500.00 | 6250500.00 | H | 45.9 | 14.5 | 5.8 | 6.0 |
| Lochiel | V456 | 239359.00 | 6248498.00 | H | 29.4 | 11.2 | 2.4 | 3.1 |
| Lochiel | V457 | 238430.00 | 6246500.00 | H | 76.7 | 5.5 | 18.4 | 3.6 |
| Lochiel | V462 | 240500.00 | 6247500.00 | H | 65.6 | 7.5 | 14.1 | 4.7 |
| Lochiel | V465 | 242500.00 | 6249500.00 | H | 68.0 | 6.1 | 14.1 | 3.6 |
| Lochiel | V466 | 239000.00 | 6247500.00 | H | 66.5 | 5.5 | 11.6 | 2.7 |
| Lochiel | V468 | 241500.00 | 6251500.00 | H | 58.2 | 13.0 | 9.8 | 7.4 |
| Lochiel | V490 | 240505.00 | 6244518.00 | H | 65.1 | 5.6 | 13.1 | 3.1 |
| Lochiel | V492 | 240438.00 | 6245499.00 | H | 56.7 | 8.5 | 8.5 | 3.9 |
| Lochiel | V499 | 239586.00 | 6250651.00 | H | 32.0 | 15.9 | 2.0 | 5.1 |
| Lochiel | V506 | 239446.00 | 6246366.00 | H | 59.0 | 7.6 | 10.3 | 3.4 |
| Lochiel | V510 | 240631.00 | 6248210.00 | H | 41.5 | 11.1 | 6.7 | 4.0 |
| Lochiel | V562 | 241000.00 | 6246500.00 | H | 51.4 | 8.5 | 6.7 | 3.5 |
| Lochiel | V563 | 241974.00 | 6249454.00 | H | 56.7 | 7.5 | 9.8 | 3.8 |
| Lochiel | V571 | 240491.00 | 6250999.00 | H | 31.6 | 18.7 | 1.3 | 6.3 |
| Lochiel | V572 | 239480.00 | 6249573.00 | H | 38.4 | 14.1 | 3.0 | 4.8 |
| Lochiel | V604 | 240454.00 | 6246804.00 | H | 55.4 | 7.6 | 9.7 | 3.4 |
| Lochiel | V632 | 240738.00 | 6250145.00 | H | 42.8 | 13.3 | 4.2 | 5.1 |
| Lochiel | V634 | 240480.00 | 6245930.00 | H | 66.3 | 10.6 | 11.9 | 5.9 |
| Lochiel | V664 | 239466.92 | 6245598.66 | H | 73.2 | 5.6 | 17.5 | 3.7 |
| Lochiel | V678 | 242248.93 | 6246499.22 | H | 70.8 | 6.9 | 12.3 | 3.4 |
| Lochiel | V679 | 241749.88 | 6246500.26 | H | 69.5 | 7.1 | 13.6 | 4.0 |
| Lochiel | V680 | 239500.82 | 6245000.58 | H | 73.3 | 6.5 | 16.6 | 4.1 |
| Lochiel | V682 | 239979.26 | 6245996.54 | H | 75.4 | 4.6 | 19.0 | 3.2 |
| Lochiel | V683 | 239000.07 | 6245999.96 | H | 47.8 | 10.7 | 5.9 | 4.1 |
| Lochiel | V684 | 240213.65 | 6245504.87 | H | 64.0 | 6.1 | 13.9 | 3.8 |
| Lochiel | V685 | 239993.95 | 6244983.98 | H | 68.8 | 6.0 | 13.2 | 3.3 |
| Lochiel | V686 | 239500.34 | 6246000.13 | H | 66.8 | 6.9 | 12.4 | 3.4 |
| Lochiel | V690 | 241500.58 | 6245996.79 | H | 73.2 | 4.2 | 16.9 | 2.6 |
| Lochiel | V691 | 242001.24 | 6245991.97 | H | 57.6 | 8.0 | 8.3 | 3.5 |
| Lochiel | V695 | 242502.08 | 6245998.34 | H | 71.5 | 4.7 | 16.9 | 3.0 |
| Lochiel | V696 | 240999.14 | 6244991.27 | H | 63.4 | 6.7 | 11.3 | 3.2 |
| Lochiel | V698 | 241499.78 | 6246999.88 | H | 73.8 | 8.2 | 16.3 | 5.2 |
| Lochiel | V699 | 241249.79 | 6247498.18 | H | 66.6 | 8.1 | 13.4 | 4.5 |

Appendix E3: Quartz and kaolinite mineral estimates (Sheet 5 of 7)

| Deposit | Borehole ID | Easting | Northing | Seam | $SiO_2$ (% db) | $Al_2O_3$ (% db) | Estimated Quartz (% db) | Estimated Kaolinite (% db) |
|---|---|---|---|---|---|---|---|---|
| Lochiel | V700 | 241748.44 | 6247998.89 | H | 69.4 | 7.0 | 14.5 | 4.1 |
| Lochiel | V701 | 241749.83 | 6248503.42 | H | 76.1 | 3.7 | 18.9 | 2.4 |
| Lochiel | V703 | 241004.74 | 6244527.62 | H | 73.5 | 4.0 | 15.4 | 2.3 |
| Lochiel | V704 | 241001.40 | 6245498.96 | H | 67.0 | 5.8 | 14.0 | 2.9 |
| Lochiel | V705 | 240999.32 | 6246039.55 | H | 68.4 | 6.6 | 12.5 | 3.4 |
| Lochiel | V706 | 241748.95 | 6247501.31 | H | 63.3 | 7.6 | 12.7 | 3.6 |
| Lochiel | V707 | 241248.65 | 6248001.39 | H | 52.4 | 9.0 | 7.5 | 3.8 |
| Lochiel | V708 | 241251.50 | 6248503.19 | H | 44.5 | 13.5 | 4.7 | 5.0 |
| Lochiel | V712 | 240793.57 | 6247905.34 | H | 46.0 | 10.4 | 6.1 | 4.4 |
| Lochiel | V713 | 240748.86 | 6247501.81 | H | 62.0 | 10.1 | 9.7 | 4.3 |
| Lochiel | V714 | 240211.76 | 6247497.37 | H | 53.5 | 10.6 | 7.4 | 4.6 |
| Lochiel | V715 | 239845.89 | 6248013.96 | H | 52.0 | 9.2 | 8.8 | 4.2 |
| Lochiel | V721 | 239500.46 | 6247500.46 | H | 56.1 | 9.0 | 7.4 | 3.7 |
| Lochiel | V722 | 240000.74 | 6246497.73 | H | 71.7 | 5.6 | 17.5 | 3.8 |
| Lochiel | V725 | 240095.62 | 6243978.67 | H | 64.8 | 3.1 | 12.6 | 1.4 |
| Lochiel | V726 | 240492.42 | 6244981.27 | H | 75.2 | 4.1 | 18.6 | 2.7 |
| Lochiel | V727 | 240100.50 | 6247130.39 | H | 60.1 | 8.3 | 10.0 | 4.1 |
| Lochiel | V731 | 238939.99 | 6248500.01 | H | 59.6 | 7.5 | 9.4 | 3.5 |
| Lochiel | V733 | 240999.60 | 6247000.17 | H | 77.2 | 5.9 | 21.2 | 4.5 |
| Lochiel | V734 | 241627.54 | 6249059.94 | H | 72.1 | 6.0 | 15.3 | 3.5 |
| Lochiel | V736 | 240999.99 | 6243500.00 | H | 82.6 | 1.2 | 24.4 | 0.9 |
| Lochiel | V742 | 241500.04 | 6243999.66 | H | 77.3 | 1.1 | 22.0 | 0.8 |
| Lochiel | V743 | 241000.04 | 6243999.66 | H | 77.4 | 1.9 | 17.3 | 1.1 |
| Lochiel | V749 | 240691.05 | 6244023.11 | H | 70.0 | 2.9 | 16.2 | 1.4 |
| Lochiel | V751 | 239151.66 | 6247546.84 | H | 56.9 | 6.8 | 9.5 | 2.8 |
| Lochiel | V753 | 239364.03 | 6247997.51 | H | 45.6 | 11.3 | 5.7 | 4.4 |
| Lochiel | V754 | 238987.31 | 6246985.82 | H | 62.7 | 7.1 | 12.2 | 3.7 |
| Lochiel | V757 | 241838.01 | 6246874.96 | H | 62.9 | 6.9 | 11.8 | 3.8 |
| Bowmans | B1 | 246007.71 | 6215504.86 | B1 | 46.2 | 3.7 | 8.7 | 1.8 |
| Bowmans | B5 | 245992.83 | 6213985.40 | B1 | 46.3 | 9.3 | 7.1 | 4.8 |
| Bowmans | V152 | 247435.00 | 6213686.00 | B1 | 55.6 | 7.6 | 12.6 | 5.2 |
| Bowmans | V180 | 246475.00 | 6214205.00 | B1 | 23.2 | 12.5 | 1.2 | 4.8 |
| Bowmans | V184 | 245046.00 | 6215014.00 | B1 | 14.9 | 7.8 | 0.6 | 1.8 |
| Bowmans | V192 | 244049.00 | 6214973.00 | B1 | 35.3 | 14.4 | 3.5 | 6.2 |
| Bowmans | V226 | 244088.00 | 6216927.00 | B1 | 49.1 | 11.7 | 8.1 | 6.1 |
| Bowmans | V242 | 245501.00 | 6216002.00 | B1 | 22.6 | 6.9 | 1.5 | 1.8 |
| Bowmans | V243 | 246727.00 | 6213251.00 | B1 | 67.7 | 8.4 | 19.1 | 7.0 |
| Bowmans | V255 | 245133.00 | 6215560.00 | B1 | 32.7 | 14.3 | 2.1 | 4.9 |
| Bowmans | V257 | 245735.00 | 6215076.00 | B1 | 23.8 | 6.9 | 1.8 | 1.9 |
| Bowmans | V258 | 245913.00 | 6214617.00 | B1 | 24.7 | 11.6 | 1.7 | 4.2 |
| Bowmans | V259 | 246405.00 | 6215083.00 | B1 | 24.1 | 7.7 | 2.6 | 2.8 |
| Bowmans | V267 | 245885.00 | 6214805.00 | B1 | 31.8 | 10.6 | 2.5 | 3.7 |
| Bowmans | V320 | 245950.70 | 6213535.10 | B1 | 74.4 | 6.3 | 28.7 | 6.8 |
| Bowmans | V321 | 245256.50 | 6214068.10 | B1 | 68.3 | 3.0 | 19.1 | 2.2 |
| Bowmans | V323 | 244557.60 | 6215500.70 | B1 | 41.1 | 6.0 | 4.5 | 2.0 |
| Bowmans | V327 | 243841.70 | 6216340.10 | B1 | 38.2 | 20.7 | 2.4 | 7.2 |
| Bowmans | V328 | 247328.10 | 6214552.00 | B1 | 41.2 | 10.9 | 5.0 | 4.8 |
| Bowmans | B1 | 246007.71 | 6215504.86 | B3 | 30.8 | 4.4 | 5.7 | 1.7 |
| Bowmans | B2 | 246500.17 | 6213499.69 | B3 | 25.4 | 8.2 | 1.9 | 2.8 |
| Bowmans | B3 | 246499.90 | 6211999.56 | B3 | 34.1 | 1.5 | 5.8 | 0.6 |
| Bowmans | B5 | 245992.83 | 6213985.40 | B3 | 23.1 | 4.5 | 2.7 | 1.2 |
| Bowmans | V152 | 247435.00 | 6213686.00 | B3 | 34.3 | 5.9 | 3.9 | 2.0 |

Appendix E3: Quartz and kaolinite mineral estimates (Sheet 6 of 7)

| Deposit | Borehole ID | Easting | Northing | Seam | $SiO_2$ (% db) | $Al_2O_3$ (% db) | Estimated Quartz (% db) | Estimated Kaolinite (% db) |
|---|---|---|---|---|---|---|---|---|
| Bowmans | V153 | 247539.00 | 6212837.00 | B3 | 18.7 | 8.0 | 1.0 | 2.1 |
| Bowmans | V180 | 246475.00 | 6214205.00 | B3 | 21.7 | 7.3 | 3.8 | 2.1 |
| Bowmans | V184 | 245046.00 | 6215014.00 | B3 | 27.9 | 12.4 | 3.4 | 4.4 |
| Bowmans | V217 | 245960.00 | 6211972.00 | B3 | 28.7 | 6.6 | 4.1 | 2.2 |
| Bowmans | V242 | 245501.00 | 6216002.00 | B3 | 44.8 | 5.5 | 4.9 | 1.8 |
| Bowmans | V243 | 246727.00 | 6213251.00 | B3 | 27.7 | 6.8 | 4.6 | 2.9 |
| Bowmans | V255 | 245133.00 | 6215560.00 | B3 | 44.2 | 9.8 | 7.5 | 3.7 |
| Bowmans | V257 | 245735.00 | 6215076.00 | B3 | 11.5 | 4.5 | 0.8 | 1.3 |
| Bowmans | V258 | 245913.00 | 6214617.00 | B3 | 16.9 | 5.5 | 1.0 | 1.3 |
| Bowmans | V259 | 246405.00 | 6215083.00 | B3 | 8.6 | 6.3 | 0.2 | 1.0 |
| Bowmans | V267 | 245885.00 | 6214805.00 | B3 | 22.5 | 7.9 | 2.9 | 2.4 |
| Bowmans | V319 | 244628.20 | 6212863.30 | B3 | 29.2 | 8.1 | 2.8 | 2.9 |
| Bowmans | V320 | 245950.70 | 6213535.10 | B3 | 22.3 | 5.8 | 3.0 | 2.5 |
| Bowmans | V321 | 245256.50 | 6214068.10 | B3 | 56.3 | 3.6 | 10.6 | 1.8 |
| Bowmans | V322 | 244486.00 | 6214042.00 | B3 | 50.5 | 8.3 | 9.7 | 5.0 |
| Bowmans | V323 | 244557.60 | 6215500.70 | B3 | 60.5 | 10.0 | 12.1 | 6.3 |
| Bowmans | V327 | 243841.70 | 6216340.10 | B3 | 69.4 | 11.2 | 14.5 | 7.3 |
| Bowmans | V328 | 247328.10 | 6214552.00 | B3 | 30.7 | 4.9 | 4.1 | 2.0 |
| Bowmans | V330 | 245768.60 | 6211939.10 | B3 | 51.6 | 1.8 | 8.4 | 0.7 |
| Bowmans | V335 | 246447.50 | 6211202.10 | B3 | 41.5 | 3.3 | 7.7 | 1.3 |
| Bowmans | V336 | 246572.00 | 6212722.80 | B3 | 36.8 | 2.1 | 4.0 | 0.6 |
| Bowmans | V340 | 248093.60 | 6212114.50 | B3 | 45.8 | 6.0 | 8.5 | 2.4 |
| Bowmans | B1 | 246007.71 | 6215504.86 | C | 39.3 | 3.5 | 6.9 | 1.2 |
| Bowmans | B2 | 246500.17 | 6213499.69 | C | 23.0 | 5.4 | 2.3 | 1.7 |
| Bowmans | B3 | 246499.90 | 6211999.56 | C | 21.0 | 5.7 | 3.5 | 2.0 |
| Bowmans | B4 | 246499.94 | 6212499.73 | C | 22.6 | 4.3 | 2.5 | 1.5 |
| Bowmans | B5 | 245992.83 | 6213985.40 | C | 19.8 | 3.4 | 1.8 | 1.0 |
| Bowmans | V142 | 244000.00 | 6208147.00 | C | 12.7 | 5.1 | 0.7 | 1.5 |
| Bowmans | V144 | 244564.00 | 6210353.00 | C | 15.9 | 2.7 | 2.4 | 1.0 |
| Bowmans | V145 | 244624.00 | 6207484.00 | C | 8.3 | 3.9 | 0.5 | 1.2 |
| Bowmans | V152 | 247435.00 | 6213686.00 | C | 29.5 | 0.9 | 2.6 | 0.2 |
| Bowmans | V153 | 247539.00 | 6212837.00 | C | 24.2 | 3.9 | 2.3 | 1.1 |
| Bowmans | V180 | 246475.00 | 6214205.00 | C | 30.8 | 5.1 | 4.4 | 1.6 |
| Bowmans | V184 | 245046.00 | 6215014.00 | C | 28.8 | 3.8 | 3.4 | 1.5 |
| Bowmans | V195 | 246087.00 | 6209064.00 | C | 25.1 | 9.0 | 2.4 | 3.7 |
| Bowmans | V217 | 245960.00 | 6211972.00 | C | 17.5 | 7.2 | 3.4 | 2.1 |
| Bowmans | V242 | 245501.00 | 6216002.00 | C | 67.1 | 3.6 | 13.5 | 1.9 |
| Bowmans | V243 | 246727.00 | 6213251.00 | C | 16.1 | 9.7 | 0.9 | 3.0 |
| Bowmans | V255 | 245133.00 | 6215560.00 | C | 56.1 | 2.1 | 8.5 | 0.8 |
| Bowmans | V257 | 245735.00 | 6215076.00 | C | 69.8 | 0.9 | 16.1 | 0.5 |
| Bowmans | V258 | 245913.00 | 6214617.00 | C | 50.3 | 2.6 | 11.5 | 1.3 |
| Bowmans | V259 | 246405.00 | 6215083.00 | C | 23.9 | 4.2 | 3.8 | 0.7 |
| Bowmans | V267 | 245885.00 | 6214805.00 | C | 31.7 | 1.5 | 4.4 | 0.4 |
| Bowmans | V319 | 244628.20 | 6212863.30 | C | 41.9 | 7.2 | 5.8 | 3.2 |
| Bowmans | V320 | 245950.70 | 6213535.10 | C | 46.5 | 6.4 | 8.3 | 2.9 |
| Bowmans | V321 | 245256.50 | 6214068.10 | C | 47.9 | 2.8 | 7.1 | 1.1 |
| Bowmans | V322 | 244486.00 | 6214042.00 | C | 62.7 | 3.8 | 17.3 | 2.9 |
| Bowmans | V323 | 244557.60 | 6215500.70 | C | 34.7 | 2.5 | 3.3 | 0.7 |
| Bowmans | V327 | 243841.70 | 6216340.10 | C | 74.8 | 1.1 | 20.9 | 0.8 |
| Bowmans | V328 | 247328.10 | 6214552.00 | C | 45.6 | 1.1 | 6.4 | 0.4 |
| Bowmans | V330 | 245768.60 | 6211939.10 | C | 30.5 | 3.2 | 3.9 | 1.1 |
| Bowmans | V335 | 246447.50 | 6211202.10 | C | 34.2 | 5.8 | 5.6 | 1.6 |

Appendix E3: Quartz and kaolinite mineral estimates (Sheet 7 of 7)

| **Deposit** | **Borehole ID** | **Easting** | **Northing** | **Seam** | **$SiO_2$** (% db) | **$Al_2O_3$** (% db) | **Estimated Quartz** (% db) | **Estimated Kaolinite** (% db) |
|---|---|---|---|---|---|---|---|---|
| Bowmans | V336 | 246572.00 | 6212722.80 | C | 36.7 | 5.9 | 5.2 | 2.6 |
| Bowmans | V340 | 248093.60 | 6212114.50 | C | 42.5 | 7.2 | 6.5 | 2.6 |
| Bowmans | V345 | 245178.60 | 6210976.60 | C | 36.4 | 5.2 | 5.4 | 2.4 |

Note: Analytical determinations of $SiO_2$ and $Al_2O_3$ conform to AS 1038.14.1 (1979)